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THE GEOGRAPHICAL CYCLE IN AN ARID CLIMATE

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Normal and special cycles.—The scheme of the geographical cycle is usually developed with respect to a land surface under ordinary climatic conditions, not so dry but what all basins overflow and all parts of the surface have continuous drainage to the sea, nor so cold but what the snow of winter all disappears in summer. The term "normal climate" has been applied to such conditions, and "normal cycle" to the scheme that embodies them. It is chiefly this scheme that I have elsewhere treated on various occasions (*a*, *b*, *c*, *h*).[1]

The general scheme of the geographical cycle needs adaptation to two special climates: one, glacial; the other, arid. The glacial cycle received brief attention in one of my papers (*d*) five years ago, but now needs supplement in view of the later studies by Richter, de Martonne, Lawson, and others, as to the forms of glaciated mountains, and in view of the theory announced by Gilbert that glaciers are not buoyed up while they rest on the sea bottom, and that they may therefore erode their channels deep below sea-level. The arid cycle has not been considered as a whole, although special studies of desert conditions have been made by various observers, notably by Walther. The following general considerations are based on the work of others as well as on my own observations in the arid regions of the western United States and of western Asia; they are presented for the most

[1] See list of references at the end of this article.

part in an intentionally and avowedly deductive manner, but they are checked by facts from stage to stage. My especial indebtedness to Passarge is stated below.

The arid climate.—The essential features of the arid climate, as it is here considered, are: so small a rainfall that plant growth is scanty, that no basins of initial deformation are filled to overflowing, that no large trunk rivers are formed, and hence that the drainage does not reach the sea.

The agencies of sculpture and their opportunities for work in arid regions are peculiar in several respects. The small rainfall and the dry air reduce the ground water to a minimum. In its absence, weathering is almost limited to the surface, and is more largely physical than chemical. The streams are usually shorter than the slopes, and act as discontinuously at their lower as at their upper ends. The scarcity of plant growth leaves the surface relatively free to the attack of the winds and of the intermittent waters. Hence, in the production of fine waste, the splitting, flaking, and splintering of local weathering are supplemented rather by the rasping and trituration that go with transportation than by the chemical disintegration that characterizes a plant-bound soil.

No special conditions need be postulated as to the initiation of the arid cycle. The passive earth's crust may be (relatively) uplifted and offered to the sculpturing agencies with any structure, any form, and any altitude, in dry as well as in moist regions.

Initial stage.—Let consideration be given to an uplifted region of large extent over which an arid climate prevails. Antecedent rivers, persisting from a previous cycle against the deformations by which the new cycle is introduced, must be rare, because such rivers should be large, and large rivers are unusual in an arid region. Consequent drainage must prevail. The initial slopes in each basin will lead the wash of local rains toward the central depression, whose lowest point serves as the local baselevel for the district. There will be as many independent centripetal systems as there are basins of initial deformation; for no basin can contain an overflowing lake, whose outlet would connect two centripetal systems: the centripetal streams will not always follow the whole length of the centripetal slopes; most of the streams of each basin system will wither away after descending from

the less arid highlands to the more arid depressions. Each basin system will therefore consist of many separate streams, which may occasionally, in time of flood or in the cooler season of diminished evaporation, unite in an intermittent trunk river, and even form a shallow lake in the basin bed, but which will ordinarily exist independently as disconnected headwater branches.

Youthful stage.—In the early stage of a normal cycle the relief is ordinarily and rapidly increased by the incision of consequent valleys by the trunk rivers that flow to the sea. In the early stage of the arid cycle the relief is slowly diminished by the removal of waste from the highlands, and its deposition on the lower gentler slopes and on the basin beds of all the separate centripetal drainage systems. Thus all the local baselevels rise. The areas of removal are in time dissected by valleys of normal origin: if the climate is very arid, the uplands and slopes of these areas are either swept bare, or left thinly veneered with angular stony waste from which the finer particles are carried away almost as soon as they are weathered; if a less arid climate prevails on the uplands and highlands, the plants that they support will cause the retention of a larger proportion of finer waste on the slopes. The areas of deposition are, on the other hand, given a nearly level central floor of fine waste, with the varied phenomena of shallow lakes, playas, and salinas, surrounded with graded slopes of coarser waste. The deposits thus accumulated will be of variable composition and, toward the margin, of irregular structure. The coarser deposits will exhibit a variety of materials, mechanically comminuted, but not chemically disintegrated, and hence in this respect unlike the less heterogeneous deposits of humid climates from which the more easily soluble or decomposable minerals have been largely removed. The finer deposits will vary from sand and clay to salt and gypsum. The even strata that are supposed to characterize lake deposits may follow or precede irregular or cross-bedded strata, as the lake invades or is invaded by the deposits of streams or winds. While many desert deposits may be altogether devoid of organic remains, others may contain the fossils of land, stream, or lake organisms.

The Basin Range province of the western United States gives examples of dissected mountains from which descend many withering streams that belong to separate drainage systems of the kind

above described, and of basins aggraded with the waste from the dissected mountains. Trunk streams are rare. The initial relief has been decreased, although the basin floors are from 3,000 to 5,000 feet above sea-level. Persia and Tibet give further illustrations of the same relation. In the latter region the intermont basins often contain saline lakes; but the stage of development there reached is not yet clear, because the origin of the ranges and basins is not, as a rule, considered by Tibetan explorers. It should not, however, be inferred that the separation of the many drainage systems in regions such as those of Persia and Tibet is the result of any special peculiarity in the initial deformation of the surface, essentially unlike the deformation of other regions of normal climate, where large unified drainage systems are the rule. The latter regions may initially have had as many basins of deformation as the former, but the more plentiful rainfall of normal climate has enabled their rivers to cut down the basin rims. This principle has been pointed out by Penck (*a*, p. 87; *b*, p. 159) and others. The initial relief may be of coarse pattern, as in central Asia, where the vast aggraded plains of eastern and western Turkestan are separated by a broadly uplifted and deeply dissected mountainous area; or of finer pattern, as in the Basin Range province just mentioned, where many small ranges separate nearly as many small basins. The progress of evolution through the cycle, and the arrangement of forms at successive stages, will be much affected by these unlike initial conditions.

Streams, floods, and lakes are the chief agencies in giving form to the aggraded basin floors, as well as to the dissected basin margins in the early stages of the cycle; but the winds also are of importance: they do a certain share of erosion by sand-blast action; they do a more important work of transportation by sweeping the granular waste from exposed uplands and depositing it in more sheltered depressions, and by raising the finer dust high in the air and carrying it far and wide before it is allowed to settle. Wind-action is, moreover, peculiar in not being guided by the slopes or restrained by the divides which control streams and stream systems. It is true that the winds, like the streams, tend in a very general way to wear down the highlands and to fill up the basins; but sand may be drifted uphill—dunes may be seen climbing strong slopes and escarpments

in Arizona and Oregon—while fine dust carried aloft in whirlwinds and dust-storms is spread about by the upper currents with little regard to the slopes of the land surface far below. Sand may be drifted, and dust may be in this way carried outside of the arid region from which it was derived. Wind-erosion may, furthermore, tend to produce shallow depressions or hollows; for the whole region is the bed of the wind, and is therefore to a certain extent analogous to the bed of a river, where hollows are common enough; but in the early stages of the cycle in a region where the initial relief was strong, the action of the wind is not able to make hollows on the original slopes that are actively worked upon, and for a time even steepened, by streams and floods. Hence in the youthful stage wind-blown hollows are not likely to be formed.

It is important to notice that a significant, though small, share of wind-swept or wind-borne waste may be carried entirely outside of or "exported" from an arid region. It may be deposited on neighboring lands, where it will be held among the grass of a less arid climate, as long ago suggested by Richthofen; it may even be held down on coastal lands by the dew, as has been suggested for certain districts in Morocco by Fischer; it may fall into the sea, as is proved by the sand that gives a ruddy tinge to the sails of vessels in the Atlantic to leeward of the Sahara, and by the sand grains that are dredged up with true pelagic deposits from the bottom of that part of the Atlantic. It may therefore be expected that the progress of erosion and waste exportation in a desert region should be associated with the deposit of fine waste, as in loess sheets, on the neighboring less arid regions, especially down the course of the prevailing winds. In regions of weak and variable winds the process of sand and dust exportation must be extremely slow; in regions of steady winds it must still be vastly slower than the ordinary rate of waste removal in young or mature regions of plentiful rainfall and normal rivers. Yet it is by this slow process of exportation that the mean altitude of an arid region, such as is here considered, will be continually decreased; hence the earlier stages of the arid cycle are expectably longer than the corresponding stages of the normal cycle.

In the normal cycle the youthful stage is characterized by the headward growth of many subsequent streams, chiefly along belts

of weak structures that are laid bare on the valley sides of the larger consequent streams. In the arid cycle subsequent streams have a smaller opportunity for development; first because all the belts of weak structure under the basin deposits are buried out of reach; second, because, in the absence of deep-cutting trunk rivers, many belts of weak structure are but little exposed. In so far, however, as the highlands are dissected by their headwater consequent streams, subsequent branches may grow out and diversify the slopes and rearrange the drainage.

Mature stage.—Continued erosion of the highlands and divides, and continued deposition in the basins, may here and there produce a slope from a higher basin floor across a reduced part of its initial rim to a lower basin floor. Headward erosion by the consequent or subsequent streams of the lower basin will favor this change, which might then be described as a capture of the higher drainage area. Aggradation of the higher basin is equally important, and a change thus effected might be described as an invasion of the lower basin by waste from the higher one; this corresponds in a belated way to the overflow of a lake in a normal cycle. There may still be no persistent stream connecting the two basins, but whenever rain falls on the slope that crosses the original divide, the wash will carry waste from the higher to the lower basin. Thus the drainage systems of two adjacent basins coalesce, and with this a beginning is made of the confluence and integration of drainage lines which, when more fully developed, characterize maturity. The intermittent drainage that is established across the former divide may have for a time a rather strong fall; as this is graded down to an even slope, an impulse of revival and deeper erosion makes its way, wave-like, across the floor of the higher basin and up all its centripetal slopes. The previously aggraded floor will thus for a time be dissected with a bad-land expression and then smoothed at a lower level; the bordering waste slopes will be trenched and degraded. At the same time, the lower basin floor will be more actively aggraded. If there is a sufficient difference of altitude between the two basins, all the waste that had been, in a preliminary or youthful view of the case, gathered in the higher basin, will in time be transferred to the lower basin; and thus a larger relation of drainage lines, a longer distance of intermittent

transportation, a more continuous area of bed-rock in the higher areas, and a more general concentration of waste in the lowest basins will be established. The higher local baselevels are thus, by a process of slow, inorganic natural selection, replaced by a smaller and smaller number of lower and lower baselevels; and with all this go a headward extension of graded piedmont slopes, a deeper dissection of the highlands, and a better development of their subsequent and adjusted drainage. The processes of drainage adjustment are, however, at the best, of less importance here than in the normal cycle, because of the absence of main valleys, deep-cut by trunk rivers, and the resulting deficient development of deep-set subsequent streams, as has already been suggested.

Some changes of this kind have probably taken place in the Basin Range province of Utah and Nevada, but more field work will be needed before they can be safely pointed out. Indeed, it seems to be the case that certain changes of an opposite kind have taken place; the long intermont troughs appear to be here and there subdivided into separate basins by the undue growth of certain detrital fans where large valleys have been opened in the neighboring ranges; but this condition of things will pass when the mountains are worn lower and the waste is discharged from them less actively.

As the coalescence of basins and the integration of stream systems progress, the changes of local baselevels will be fewer and slower, and the obliteration of the uplands, the development of graded piedmont slopes, and the aggradation of the chief basins will be more and more extensive. The higher parts of the piedmont slopes may be rock-floors, thinly and irregularly veneered with waste, as has been described by Keyes for certain basins (bolsons) in New Mexico; here, as well as upon the aggraded slopes and plains, sheet-flood action will prevail, as explained by McGee. The area occupied during early maturity by the three different kinds of surface—dissected highlands or mountains, graded piedmont slopes of rock or waste, and aggraded central plains with playas, salinas, or lakes—will depend on the initial relief, on the rock structure and its relation to desert weathering, on the percentage of material exported by the winds, and on the climate itself.

It is worth noting that, although the activity of streams and floods

decreases with the decrease of relief and of slope, the activity of the winds is hardly affected as maturity advances. The winds do not depend on the gradient of the land surface for their gravitative acceleration; they may blow violently and work efficiently on a level surface. Whirlwinds are, indeed, most active on true plains. It may be that smooth plains are never swept by winds so violent as the blasts which attack highlands and mountains; but it is probable that the effective action of the winds is greater on a generally plain surface than on one of strong relief, where the salient ridges and peaks consist largely of firm rock, and where the loose waste is sheltered in re-entrant valleys. Moreover, it is in very great part on the plains that the winds of ordinary strength drift the sand about, and from the plains that whirlwinds and dust-storms raise the finest waste high enough for exportation. It may therefore be concluded that the work of the winds is but little, if any, impaired by the general decrease of relief that characterizes advancing maturity; and hence that their relative importance increases. Moreover, the scanty rainfall of an arid region will be decreased as its initial highlands, which originally acted as rain-provokers, are worn down; hence, as the relief weakens, the winds will more and more gain the upper hand in the work of transportation. It is conceivable that the rate of exportation of sand and dust by the winds in maturity and all the later stages of an arid cycle is more rapid than the removal of fine soil, partly or largely in solution, from a plant-covered peneplain in the later stages of a normal cycle; thus the slower work of the earlier stages of an arid cycle may be partly made good by the relatively more active work in the later stages.

As the processes thus far described continue through geological periods, the initial relief will be extinguished even under the slow processes of desert erosion, and there will appear instead large, rock-floored plains sloping toward large waste-floored plains; the plains will be interrupted only where parts of the initial highlands and masses of unusually resistant rocks here and there survive as isolated residual mountains. At the same time, deposits of loess may be expected to accumulate in increasing thickness on the neighboring less arid regions. The altitude at which the desert plain will stand is evidently independent of the general baselevel—or sea-level—and

dependent only on the original form and altitude of the region, and on the amount of dust that it has lost through wind transportation.

The most perfect maturity would be reached when the drainage of all the arid region becomes integrated with respect to a single aggraded basin-baselevel, so that the slopes should lead from all parts of the surface to a single area for the deposition of the waste. The lowest basin area which thus comes to have a monopoly of deposition may receive so heavy a body of waste that some of its ridges may be nearly or quite buried. Strong relief might still remain in certain peripheral districts, but large plain areas would by this time necessarily have been developed. In so far as the plains are rock-floored, they would truncate the rocks without regard to their structure.

There is no novelty in the idea that a mountainous region of interior drainage may be reduced to a plain by the double process of wearing down the ranges and filling up the basins, and that the plain thus formed, consisting partly of worn-down rock and partly of built-up waste, will not stand in any definite relation to the general baselevel of the ocean surface; yet the idea has seldom been applied in the interpretation of uplifts by the physiographic method. In the case of the plateaus that are now trenched by the Colorado river in northern Arizona, for example, it has usually been tacitly postulated that the baselevel with respect to which they were widely denuded in the pre-canyon cycle was the normal baselevel of the ocean, and from this postulate it has been argued that the cycle of canyon erosion was introduced by a strong uplift. My own opinion has agreed with that of Dutton and others in this respect. Yet it is not today easily demonstrated that the Arizona plateaus had exterior drainage at the time of their wide denudation; and until exterior drainage is shown to have obtained, the altitude of the plateau region during its denudation must remain uncertain. There are, however, several facts which point to the correctness of the generally accepted view: the course of the Colorado river through the Kaibab cannot easily be explained as having originated in the present cycle; it appears to have been established earlier; and it is doubtful whether there are late Tertiary basin deposits within the desert area, or wind-carried sand and loess deposits in the area to the eastward (leeward) of

sufficient volume to represent the great volume of material removed in the degradation of the plateaus.

In the case of truncated uplands elsewhere—that is, uplands whose surface truncates their structure, as in the central plateau of France—it is generally a tacit postulate, if not a proved conclusion, that the climate during their truncation was not arid, and hence it is inferred that they were worn down as peneplains with respect to normal baselevel, and that they have been uplifted since; this aspect of the problem will be considered farther on. In the meantime, there is another aspect of erosion in arid regions which, to my knowledge, has not, until recently, received attention.

The beginning of old age.—During the advance of drainage integration the exportation of wind-borne waste is continued. At the same time, the tendency of wind-action to form hollows wherever the rocks weather most rapidly to a dusty texture would be favored by the general decrease of surface slopes, and by the decrease of rainfall and of stream-action resulting from the general wearing-down of the highlands. Thus it may well happen that wind-blown hollows should be produced here and there, through the mature and later stages of the cycle, and that they should even during early maturity interfere, to a greater or less degree, with the development of the integrated drainage, described above. In any case, it may be expected that wind-blown hollows would in late maturity seriously interfere with the maintenance of an integrated drainage system. Thus it appears that, along with the processes which tend toward the mature integration of drainage, there are other processes which tend toward a later disintegration, and that the latter gain efficiency as the former begin to weaken. A strong initial relief of large pattern, a quality of rock not readily reducible to dusty waste, and an irregular movement of light winds might give the control of sculpture to the intermittent streams through youth and into maturity; in such a case maturity might be characterized by a fully integrated system of drainage slopes, with insignificant imperfections in the way of wind-blown hollows. In a second region an initial form of weaker relief, a quality of rock readily reducible to dust, and a steady flow of strong winds might favor the development of wind-blown hollows or basins, and here the process of drainage disintegration would set

in relatively early and prevent the attainment of mature drainage integration. In any case, as soon as the process of drainage disintegration begins to predominate, maturity may be said to pass into old age.

This feature of the arid cycle has no close analogy with the features recognized in the normal cycle. In the latter case, the drainage systems of maturity tend on the whole to persist, even though the streams weaken and wander somewhat—and according to theory lose some of their adjustments—in very advanced old age; in the former case, as old age advances, the integrated and enlarged drainage systems of maturity are broken up into all manner of new and local, small and variable, systems. The further results of drainage disintegration in the later stages of the cycle are even more peculiar.

Leveling without baseleveling.—The later consequences of erosion in an extensive arid region have been, as far as my reading goes, first and recently stated by Passarge, in connection with his studies of the arid regions of South Africa, as is more fully indicated below.

As the dissected highlands of maturity are worn down, the rainfall decreases, and the running streams are weakened and extinguished; thus, as has been suggested above, the winds in time would appear to gain the upper hand as agents of erosion and transportation. If such were the case, it would seem that great inequalities of level might be produced by the excavation of wide and deep hollows in areas of weak rocks. As long as the exportation of wind-swept sand and of wind-borne dust continued, no easily defined limit would be found for the depth of the hollows that might thus be developed in the surface, for the sweeping and lifting action of the wind is not cotrolled by any general baselevel. In an absolutely rainless region there appears to be no reason for doubting that these abnormal inequalities of surface might eventually produce a strong relief in a still-standing land of unchanging climate; but in the actual deserts of the world there appears to be no absolutely rainless region; and even small and occasional rainfalls will suffice, especially when they occur suddenly and cause floods, as is habitual in deserts, to introduce an altogether different régime in the development of surface forms from the rock hills and hollows which would prevail under the control of the winds alone. The prevailing absence of such hill-and-hollow forms, and the

general presence of graded wadies and of drainage slopes in desert regions, confirm this statement.

As soon as a shallow wind-blown hollow is formed, that part of the integrated drainage system which leads to the hollow will supply waste to it whenever rain falls there; the finer waste will be blown away, the coarser waste will accumulate, and thus the tendency of the winds to overdeepen local hollows will be spontaneously and effectively counteracted. As incipient hollows are formed in advancing old age, and the maturely integrated drainage system disintegrates into many small and variable systems, each system will check the deepening of a hollow by wind-action; hence no deep hollow can be formed anywhere, so long as occasional rain falls.

It is conceivable that, in some special cases, there might be a peculiar balance of the various factors involved which would result in the development of wind-carved hills and hollows, even if the region were not absolutely rainless. The occurrence of permeable sandstones might favor such a result, because the rain falling on them would sink into the ground instead of running off of it, while fine grains weathered from the sandstone would be disposed of by the winds. But for the present no desert sandstone region with hills and hollows is known while such regions with hills and valleys are common. Hence it must be inferred that even in sandstone deserts the occasional rains suffice to wash the surface and to prevent the formation of anything more than very shallow depressions.

As the drainage becomes more and more disintegrated, and the surface of the plain is slowly lowered, rock masses that most effectually resist dry weathering will remain as monadnocks—*Inselberge*, as Bornhardt and Passarge call them in South Africa. At the same time, the waste will be washed away from the gathering grounds of maturity and scattered in the shallow hollows that are formed here and there by the winds as old age approaches. The removal of the basin deposits by the winds may be delayed where the hygroscopic action of saline clays keeps the surface firm; but wherever the integrated centripetal slopes are locally reversed by the hollowing action of the wind, some of the central deposits will be washed back again and exposed to renewed search for fine material by the wind,

and thus a larger and larger part of the central waste will be redistributed and exported. As there is no relation of parts in the winds analogous to that of small branch and large trunk streams in river systems, the surface eroded by the winds need not slope toward any central area, but may everywhere be worn down essentially to the same level. The surface ever wearing down, the waste ever washed irregularly about by the variable disintegration of the drainage system and continually exported by the winds, a nearly level rock-floor, nowhere heavily covered with waste, and everywhere slowly lowering at the rate of sand and dust exportation, is developed over a larger and larger area; and such is the condition of quasi-equilibrium for old age. At last, as the waste is more completely exported, the desert plain may be reduced to a lower level than that of the deepest initial basin; and then a rock-floor, thinly veneered with waste, unrelated to normal baselevel, will prevail throughout—except where monadnocks still survive. This is the generalization that we owe to Passarge; it seems to me secondary in value only to Powell's generalization concerning the general baselevel of erosion. So long as the sea is held out, it would seem that a desert surface might be worn even below sea-level, as certain writers have pointed out in a general way (Penck, *b*, p. 167); but that such a desert should persistently maintain a plain surface while it is slowly worn lower and lower is a surprising result of deduction. Little wonder that an understanding of the possible development of rock-floored deserts of this kind, independent of baselevel, was not reached inductively in western America; for there has been so much disturbance in the way of fracture and uplift in that region during Mesozoic, Tertiary, and Quaternary time that the attainment of arid old age has not been permitted; but that the problem was not solved deductively by the present generation of American physiographers before it was encountered and solved by others in Africa serves to show how insufficient still is the use of the deductive method among us.

Passarge writes that his attention has been called to the difficulty of explaining the vast plain surfaces of South Africa by wind-action, because the wind has no baselevel of erosion, and it therefore can and must excavate considerable hollows in rock areas whose waste it can easily remove. He adds that this difficulty disappears as soon

as rain works with the wind, since the rain constantly seeks to wash waste into the hollows formed by the wind, whose tendency to make hollows is thereby counteracted.[1]

The verity of the arid cycle.—The deductive method by which most of the preceding paragraphs are characterized may be regarded by some readers as reaching too far into the field of untestable speculation. It is true that the examples of observed forms, by which the deduced forms of every stage should be matched, are as yet not described in sufficient number; but this may be because desert regions have not yet been sufficiently explored with the principles herein set forth—particularly Passarge's law—in mind. On the other hand, the examples of desert plains in South Africa, described by Passarge as plains of the Bechuana (Betschuana) type, suffice to show that the stage of widespread desert-leveling has actually been reached in that region, and thus justify all the earlier stages; for, however many land movements may have interrupted the regular progress of preceding cycles, the occurrence of widespread rock plains proves that at least the present cycle of arid erosion has been long continued without disturbance.

The levelness of the plains over wide areas is especially emphasized. Isolated mountains rise above the plains; and the combination of the two unlike forms is described under the term *Inselberglandschaft*, suggested by Bornhardt. Passarge states that these desert plains are not undulating with low hills, but true plains of great extent, from which the isolated residual mountains rise like islands from the sea. The residuals may be low mounds, only a few meters high, or lofty mountain masses, rising several thousand meters above the plains. The plain surrounds the steep slope of the mountains with a table-like evenness; there is no transitional belt of piedmont hills, and no intermediate slope (*b*, p. 194). The mountains consist of resistant rocks, such as granite, diorite, gabbro, quartzite, etc.,

[1] "Herr Geheimrath v. Richthofen machte mich auf die Schwierigkeit aufmerksam, die riesigen, faktisch ebenen Flächen durch Windwirkung zu erklären, dafür der Wind kein 'base level of erosion' bestände und er aus Gestein, das sich leicht abtragen lässt, bedeutende Vertiefungen ausarbeiten könne und müsse. Diese Schwierigkeit fällt fort, sobald spülender Regen mitarbeitet. Denn dieser sucht die durch den Wind geschaffenen Vertiefungen beständig mit Schutt—Sand, Lehm, etc.—auszufüllen, arbeitet also dem Wind entgegen" (Passarge, *b*, p. 208).

granite being the most frequent; the plains are of more easily eroded rocks, such as gneiss, schists, slates, sandstones, and limestones. The bedding of the rocks is not flat, but disturbed; the plain therefore truncates the rock structures. The rocks are not deeply decomposed, but are relatively fresh. The products of weathering are usually spread as a thin veneer on the plain; the waste does not lie in place, on the rocks from which it was weathered, but has been drifted about by wind and flood, and has gathered in slight depressions. The waste veneer increases the smoothness of the plain, but the rock surface is also a plain, as may be seen in the edge of water channels, as well as where the veneer is absent (*b*, p. 195). Neighboring areas contain extensive deposits of irregular strata, whose composition and want of fossils indicate their desert origin, as will be referred to again below. Various additional details are given, with the conclusion as above quoted: these rock-floored plains are not uplifted peneplains, but are the product of desert erosion unrelated to normal baselevel, in which occasional water-action has co-operated with more persistent wind-action.

The scheme of the arid cycle thus seems to be as well supported by appropriate facts as is the scheme of the normal cycle; it is, indeed, in one respect even better supported, for while the arid African plains are examples of old desert plains now growing still older, it is difficult to point out any large peneplain that still stands close to the baselevel with respect to which it was worn down.

Contrasted consequences of normal baseleveling and desert-leveling.—While the theory of marine planation was in vogue, it was customary to interpret all evenly truncated uplands—that is, uplands whose surface truncates their rock-structure—as uplifted plains of marine abrasion, more or less dissected since they were uplifted. When the efficacy of subaerial erosion was recognized, it became equally customary to interpret truncated uplands as once baseleveled and afterward uplifted peneplains. If Passarge's views be now accepted, it follows that no truncated uplands should, without further inquiry, be treated as having been eroded when their region had a lower stand with respect to baselevel; the possibility of their having been formed during an earlier arid climate as desert plains, without regard to the general baselevel of the ocean, must be considered and excluded before baseleveling and uplift can be taken as proved.

It may at first appear sufficient to say that high-standing desert plains can have been made only in those regions which are now desert, but this easy solution of the problem is hardly convincing. Climatic changes are known to have occurred in the past, and inasmuch as they did not all affect areas in a way that is sympathetic with the present arrangement of the zones, the possibility of a former different distribution of deserts from that which now occurs seems to be open. Pleistocene climatic changes of the glacial kind were so modern and short-lived that they have little bearing on the possibility of earlier climatic changes of another order. The more ancient records of glaciation are so distributed as to demand significant rearrangement of the present climatic conditions. The existing deserts are, moreover, of two kinds with respect to cause: some deserts, like those of Africa and Australia, are arranged chiefly with respect to the trade-wind belt; other deserts, like those of central Asia and the southwestern United States, are dependent for the most part on the extent and configuration of the surrounding highlands. When we go back as far as Cretaceous time, it should only be by evidence and not by assumption that we are led to regard a truncated upland of that date as having been baseleveled during a cycle of normal climate and afterward uplifted and dissected, instead of having been leveled above baselevel during a cycle of arid climate, and dissected in consequence of a change to a normal climate. A century ago demonstrated movements of the earth's crust were matters of astonishment; witness the surprise then felt at the discovery of fossilized marine shells in some of the loftier Alpine ranges. Today the crust is raised and lowered on the evidence of dissected peneplains, as in the Appalachian region, without exciting remark; it is now the shifting of climatic conditions that would cause dissenting surprise. It is difficult to determine how far such surprise is well founded, and how far it simply reflects the fashion of our time. Even if the climatic zones have always belted the earth as they do now, the desert areas that depend on the configuration of land and water, and of highlands and lowlands, have certainly varied through the geological ages. It is therefore desirable, wherever the question of "uplifted and dissected peneplains" is raised, to scrutinize it carefully, and to determine, if possible, whether it is really the attitude

of the earth's crust or the condition of climate that has been changed. It is likewise important to scrutinize desert plains, now standing above baselevel, to see if they may not have been formed normally as lowland plains of erosion and afterward uplifted. It is therefore necessary to inquire into these features by which baseleveled peneplains and rock-floored desert plains may be distinguished, even though the former may be uplifted with a change to an arid climate, or though the latter may be depressed with a change to a humid climate.

Passarge holds the opinion that the plains of the *Inselberglandschaft* are smoother than any peneplain can be; for he describes the desert plains as true plains, not as gently undulating surfaces. He states that water is not competent to produce such plains; its power of erosion works chiefly downward, and only by exception laterally; and he concludes that, although long-continued normal erosion may produce a peneplain—that is, a low, undulating hilly surface—it nevertheless cannot produce a surface like that of the plains in the *Inselberglandschaft*.[1] But, however difficult it may be to wait, in imagination, through the ages required to wear a low hilly region down to less and less relief by the weakened processes of weather and water erosion in the latest stages of the normal cycle, there are certainly some truncated uplands, ordinarily taken to be uplifted peneplains, whose interstream uplands are astonishingly even, and whose surface must have been, before dissection, very nearly plain over large areas; hence it does not seem to me altogether certain that a greater and a less degree of flatness can be taken to distinguish the two classes of plains.

A plain of erosion lying close to sea-level in a region of normal climate, and therefore traversed by rivers that reach the sea, but that do not trench the plain, might conceivably be a depressed desert plain standing long enough in a changed climate to have become cloaked with local soils; but it is extremely unlikely that the depression of a desert plain could place it so that it should slope gently to the

[1] Wasser ist nicht imstande solche Ebene zu erodieren. Seine Erosionskraft wirkt hauptsächlich in die Tiefe, nur ausnahmsweise in die Breite. . . . . Bei sehr lang andauernder Abtragung kann wohl eine 'Peneplain' zustande kommen, d. h. ein flaches welliges Hügelland, aber keine Fläche, wie die Ebenen der Inselberglandschaften" (*b*, p. 196).

seashore, and that its new-made rivers should not dissect it, and that there should be no drifted sands and loess sheets on adjoining areas, and no signs of submergence on neighboring coasts. An untrenched plain of erosion in such an attitude would be properly interpreted as the result of normal processes, long and successfully acting with respect to normal baselevel. There would therefore appear to be no serious danger of confusing an actual peneplain of normal origin, still standing close to baselevel, with a depressed plain of desert origin. For the reasons above given I am not disposed to follow Passarge in the suggestion that the old land mass of Guiana may be an *Inselberglandschaft* in the process of destruction. He cites it as a flat, gently undulating surface of gneiss, above which rise knobs and mountains of granite; the divides are so low that one may pass in canoe between the headwaters of the Orinoco and Amazon systems (*b*, p. 194). Until further details are given, it would seem appropriate to regard this region, like the interior of Brazil to which Lapparent refers (*a*, p. 148), as an example of a normal peneplain, not raised so as to be attacked by its rivers.

In the same way a high-standing plain of erosion in a desert region might be possibly explained as an evenly uplifted peneplain whose climate had in some way been changed from humid to arid, whose deep weathered soils had been removed and replaced by thin sheets of stony, sandy, or saline waste, and whose residual reliefs had been modified to the point of producing shallow basins. But in this case there should be some indications of recent uplift around the margin of the area, either in the form of uplifted marine formations whose deposition was contemporaneous with the erosion of the peneplain, or in the form of fault-escarpments separating the uplifted from the non-uplifted areas. Moreover, it is extremely unlikely that the uplift of an extensive peneplain could place it in so level a position that it should not suffer dissection even by desert agencies; hence a high-standing desert plain is best accounted for by supposing that it has been leveled in the position that it now occupies. According to Passarge, there are no sufficient indications of elevation associated with the South African desert plains, and their explanation as the product result of long-continued desert erosion in a still-standing region would therefore seem to be assured.

Whether an appropriate deposit of wind-borne waste is to be found on neighboring regions is not yet made clear.

It should not, however, be overlooked that there is some danger of misreading the history of a depressed desert plain which has been by a moderate amount of normal weathering and erosion transformed into a normal peneplain; and of an uplifted peneplain which has been by a moderate amount of arid weathering and erosion transformed into a typical desert plain; the danger of error here is similar to that by which a peneplain, wave-swept and scoured during submergence, might be mistaken for a normal plain of marine abrasion. The consequences of error in these cases of actual plains are, however, not so serious as in those which may arise in connection with dissected plains; for this class of forms is of common occurrence, and mistakes in explaining their origin as uplifted peneplains or as changed-climate desert plains might therefore be of frequent and widespread occurrence. It is therefore desirable to search out those features by which normal peneplains, uplifted and dissected, may be distinguished from desert plains, dissected after a change to humid climate.

If a normal peneplain be uplifted, its already adjusted streams will carry their adjustments still farther in the new cycle. The high degree of adjustment of streams to structures in the Pennsylvania Appalachians and in the mediæval coastal plain of central England therefore suggests that the former surface of truncation, beneath which the present lower lands have been etched out, was a normal peneplain, uplifted. If a normal peneplain be tilted, its depressed part will soon be submerged and covered with marine deposits; and this part may, by later uplift, be associated with the elevated and dissected part. The marine deposits of our Atlantic and Gulf coastal plain, certain basal strata of continental origin excepted, seem to lie upon a depressed part of the Appalachian peneplain, and thus confirm the evidence of normal baseleveling derived from the adjusted drainage of the uplifted and dissected part of the same peneplain; the basal strata just mentioned contain fossil land plants of normal climate and confirm the conclusion. The now dissected uplands of Brittany and of the Ardennes are adjoined or overlapped by marine deposits which give strong suggestion of normal pene-

planation, as shown by Lapparent (*b*). Disturbances of the arid cycle are followed by consequences of other kinds.

Interruptions and modifications of the arid cycle.—A land mass suffering erosion under an arid climate may, as in the normal cycle, suffer interruption in the regular progress of its changes by movement of any kind at any stage of development. If, for example, integration of drainage has advanced so far that the number of original basins is reduced by half, the number may be increased again by renewed deformation; or if the integration of drainage has reached a mature stage, the drainage may be thrown into disorder again by a more or less gentle warping of the region. In all such cases a new cycle may be regarded as having been initiated; its initial forms will be the eroded forms developed during the preceding incomplete cycle, and displaced by the movements through which the preceding cycle was closed. The work of the new cycle, thus initiated, then goes on as before; but with interruptions of this kind we are not here particularly concerned, because they offer no special difficulty of explanation or interpretation.

It is otherwise when interruptions or modifications of the arid cycle occur after old age is well advanced, for the desert plains then developed may, under certain conditions, come to imitate uplifted undissected peneplains, as has already been partly considered in the preceding section.

Uniform uplift or depression, by which a normal peneplain is so immediately and significantly modified, will not interrupt the regular process of degradation on a desert plain in an arid cycle. It is perhaps in part for this reason that actual examples of rock-floored desert plains appear to be more common than actual examples of peneplains. Depression would drown a peneplain, and elevation would cause its dissection; but, unless carried to an extreme, neither of these movements would greatly affect the slow degradation of a desert plain. Unequal movements, whereby a desert plain is warped or slanted, are of more importance and are probably of more common occurrence.

If an old rock-floored desert plain be gently warped or tilted, marine submergence is not likely to follow immediately, but the regular continuation of general degradation will be interrupted. The

patches and veneers of waste will be washed from the higher to the lower parts of the warped surface; the higher parts, having an increased slope, might be somewhat dissected, and would certainly be exposed to more active degradation than before, until they were worn down to a nearly level plain again. The lower parts would receive the waste from the higher parts, and the continuance of this process of concentration would in time cause the accumulation of extensive and heavy deposits in the lower areas. Such deposits will be, as a rule, barren of fossils; the composition, texture, and arrangement of their materials will indicate the arid conditions under which they have been weathered, transported, and laid down; their structures will seldom exhibit the regularity of marine strata, and they may reach the extreme irregularity of sand-dune deposits. If warping continues, the desert deposits may gain great thickness; their original floor may be depressed below sea-level, while their surface is still hundreds or thousands of feet above sea-level.

Passarge gives a number of instances which he groups under the Banda type (*b*, p. 200) that seem to illustrate this phase of the arid cycle, although he ascribes the barren sandstones of this type to a weakening in the activity of the winds, rather than to a tilting of the region. Here the upper parts of monadnocks—*Inselberge*—rise above a broad deposit of barren continental sandstones; the intermont plains, being buried, are matters of interference. Examples of this type are mentioned in West Australia as well as in Africa.

If a change from an arid toward a moister climate causes a drainage discharge to the sea, a dissection of the plain will ensue. The valleys thus eroded cannot expectably exhibit any great degree of adjustment to the structures, because the stream courses will result from the irregular patching together of the pre-existing irregularly disintegrated drainage. This peculiar characteristic, taken together with the absence of neighboring uplifted marine deposits, will probably suffice in most cases to distinguish desert plains, dissected by a change to a moister climate, from peneplains dissected in consequence of upilft; but there still might be confusion with peneplains dissected by superposed streams.

Passarge gives two types of desert plains with a modified climate. The first or Kordofan type (*b*, p. 200) is marked by a slight increase

of rainfall, sufficient to introduce a steppe vegetation, but not sufficient to form rivers that shall reach the sea. In this case the larger residual mountain masses come to be surrounded by washed deposits coarser near the mountain base, finer farther forward, and at last grading into swampy areas with dark rich soil. Such deposits are said to be well developed in Kordofan, where the buried eroded plain between the mountains has been revealed by well borings, and where basins in the buried plain are indicated by certain unusual accumulations of ground water. The second or Adamaua type (*b*, p. 201) includes an example of more abundant rainfall, and therefore exhibits the dissection of what is taken to have been a desert plain with *Inselberge;* but the relation of streams to structures is not mentioned. Finally a Rovuma type (*b*, p. 202) is instanced on the authority of Bornhardt, in which marine Cretaceous strata of moderate thickness lie upon a plain whose erosion is ascribed to pre-existing desert conditions.

Diversion of desert drainage to exterior discharge.—The development of desert plains without regard to normal baselevel is possible only so long as they are interior basins, without drainage discharge to the sea. The maintenance of this essential condition is imperiled by small area, great altitude, no inclosing mountains, strong exterior slopes to the sea, and the occurrence of heavy rainfall on the exterior slopes. A small desert island would have no room for the production of interior basins by the processes of initial deformation, or for their maintenance against the attack of exterior streams. The absence of inclosing mountains around a continental arid region would permit the development of escaping drainage systems, so that when mature integration was reached, it might be developed with respect to normal baselevel, instead of with respect to a local interior baselevel; the Sonoran district of Mexico, as described by McGee, seems to offer examples of this kind. Great altitude of an arid region and strong exterior slopes would give strength to attacking exterior streams, and no advantage to the interior drainage; some of the basins of Tibet have already been invaded by the headwater erosion of Himalayan streams, for here the unfavorable conditions of great altitude in the basins, strong exterior slopes, and heavy exterior rainfall are all combined.

On the other hand, great area, moderate altitude, inclosure by mountain barriers, and small exterior rainfall are favorable to the leveling of interior desert plains; and to these favoring conditions should be added a long geological period of quiet. The greater the area and the less the altitude, the less the opportunity that exterior streams will have to establish relations with the interior streams. The higher the inclosing mountains, the longer the interior region will be left to itself, but the more dust it will have to export before a general rock-floor can be developed; the desert of Gobi offers an example of this kind, for its surface must long continue to suffer aggradation before the lofty ranges around its depressed surface are worn down to its level. South Africa would seem to offer, according to the descriptions by Passarge, excellent opportunity for the successful advance of the arid cycle far into old age, because of the large extent of the land area, its sufficient height and inclosure, its long-undisturbed history, and its persistently arid climate.

It thus seems evident that the conditions necessary for desert-leveling are actually present in greater or less degree in different parts of the world.

The scheme of the arid cycle as an aid to observation.—The normal cycle has now been practically used by so many observers, and with so many advantageous results, that it is not unfair to expect similar advantage from the use of the arid cycle as an aid to observation in regions where it may be appropriately applied. Certain it is that many observations now on record with regard to arid regions do not suffice to indicate clearly the stage of erosion in the arid cycle there reached; and this, not because the observers had either reason or wish to dissent from the principles of the scheme, but because it was not consciously present in their minds when the observations were made. The same is often true of the scheme of the normal cycle. In both cases the failure of the observant explorer to refer the facts that he finds to some comprehensive scheme for their systematic treatment not only results in the accidental overlooking of certain significant facts and in the insufficient description of others, but it leaves the reader in great difficulty when he tries to visualize what the observer has seen. It is as if the writer and the reader had no common language in which the observations and thoughts of the one

should be transmitted to the other. It would be far otherwise if the description of a desert region were undertaken systematically in view of what seems to be the essential sequence of changes in all deserts; that is, if the mountains and basins, the rock plains and waste plains, the stream channels, the playas and the lakes, were all treated in view of their place in the cycle of changes through which they must be running. It is chiefly as an aid to observation and record, and as an aid to the understanding of observations thus recorded, that the scheme of the arid cycle may come to be of service.

It would be fitting to accompany an article of this kind with a larger number of actual examples than have been here introduced; but in the endeavor to find appropriate examples, the interpretation of the observations of various writers in view of the scheme here submitted has not seemed safe enough to make it worth while to undertake it. Safe interpretation needs the conscious application of the scheme by the observer in the field. When thus applied, it is to be hoped that the scheme of the arid cycle may lead to the detection of many facts concerning the evolution of land forms in desert regions that have thus far escaped notice. In the meantime, the scheme must remain in great part speculative.

The bearing of the arid cycle on theories of elevation and depression. —There is another aspect of the case which, to my mind, not only gives sufficient justification for all the speculation here presented, but makes one regret that it was not undertaken sooner; for in that case certain theoretical discussions would have earlier gained a firm foundation.

In a recent discussion of "The Bearing of Physiography on Suess' Theories" (*f*), I have urged that the occurrence of high-standing and isolated peneplains could not be the result of the depression of the surrounding lands—as is advocated by Suess—unless all the oceans and their associated lowlands on other continents were also depressed at the same time and by the same amount. The necessity of accepting world-wide crustal movements may, however, be avoided, if the high-standing truncated uplands are regarded as the result of local uplifts of formerly low-standing peneplains. This alternative conclusion is so simple and economical that it is accepted by many geologists and geographers; and it seems well based as long as one

believes that the even uplands can have been truncated only by peneplanation close to sea-level. As soon, however, as it is recognized that leveling may be accomplished in an arid region without baseleveling, it is no longer necessarily the case that truncated uplands represent uplifted peneplains; the uplands may perhaps be parts of ancient desert plains, originally denuded at their present altitude; and until this possibility is excluded, their isolated position may be explained by the depression of the surrounding lands, as Suess has supposed, without corresponding change in the level of the oceans and the other continents.

In the case of the truncated uplands or *horsts* of central Germany, there appears to be good geological reason for associating them with the denuded areas of the Ardennes and of Brittany, as described by Lapparent (*b*), and thus concluding that they were all low-lying peneplains before they were uplifted. In the case of the plateaus of northern Arizona, the evidence of normal peneplanation is less complete; yet, as above stated, it still seems probable that these plateaus were denuded with respect to normal baselevel, and that the canyon was cut across their surface in consequence of a later uplift with respect to sea-level. The Bural-bas-tau, a flat-topped range, and the associated plateau-like highlands in the Tian Shan system, also need reconsideration in view of the possibility of desert-leveling. I have treated the Bural-bas-tau (*e*, *f*, *g*), and Huntington has treated the associated highlands as uplifted peneplains. Friederichsen, on the other hand, while recognizing the highland region as a *Denudationsfläche*, has hesitated to treat it as a once low-lying peneplain, because of the possibility of its erosion above baselevel in a region of inland drainage. If such were the case, it need not have had that close relation to baselevel that is to be expected in a normal peneplain. Nevertheless, the truncated highlands and mountain tops in the Tian Shan seem to be closely related to the still low-lying plains of erosion that are drained by the Ili river to Lake Balkash, and also to the still lower-lying plain of erosion—apparently a true peneplain—that is drained by the Irtysh and the Ob to the Arctic ocean; hence the probability still seems great that the even highlands of the Bural-bas-tau represent a greatly uplifted plain, even though that plain may have been, at the time of its erosion,

a desert plain, and not a normal peneplain. It is therefore exceedingly improbable that the even-topped Bural-bas-tau, standing 12,000 or 13,000 feet above sea-level, gives any close measure of the altitude which the whole region possessed while the great erosion that it has suffered was accomplished.

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NOTE ON BAKED CLAYS AND NATURAL SLAGS IN EASTERN WYOMING

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A striking feature of the country just to the east of the Big Horn Mountains, and one which adds greatly to its picturesqueness, is the widespread development of red beds and slaglike materials in consequence of the burning-out of lignite beds in the Laramie division of the Cretaceous. The baking and accompanying reddening of the sandstones and clays have in some districts been so extensive that the landscape somewhat resembles that of the typical "Red Beds" of Jura-Trias age.

Explorers and geologists who have visited this region, from the times of Lewis and Clarke down to the present day, have noted the occurrence and characteristics of these beds, and have in most cases properly interpreted their origin. Mr. J. A. Allen, who accompanied the Northern Pacific Railroad Expedition, has given us an excellent account[1] of these beds, and has summarized the previous literature. It is the intention here merely to add a few notes on the field occurrences and something as to the microscopic characters.

At the suggestion of Professor R. D. Salisbury, Mr. A. E. Taylor and the writer spent a few days in the study of these beds during the summer of 1903. These studies were confined to the district between Gillette and Buffalo, Wyo., but beds of a similar nature give color to the landscape and exert a notable influence upon the topography over a much more extensive region. Their occurrence has been reported over practically the whole northeastern quarter of the state of Wyoming, and over an area of about equal size in southeastern Montana and adjacent parts of the Dakotas—a total extent of at least 100,000 miles. This vast region is characterized by horizontal or gently inclined strata, made up largely of clays and fine sands, with occasional seams of lignitic coal, the latter usually only a foot or two

[1] *Proceedings of the Boston Society of Natural History*, Vol. XVI (1874), pp. 246 ff.

in thickness, but occasionally reaching a thickness of eight or ten feet. The beds have been sculptured by erosion into typical "Bad Lands" forms, giving the coal beds a large area of outcrop, and thus greatly facilitating their combustion.

The ignition of the coal has in certain cases taken place through human agencies, as in the case of a bed now burning (summer of 1903) six miles west of Gillette, Wyo., which was set on fire in 1902 by laborers at work on the railroad; in most cases, however, we must attribute their ignition to spontaneous combustion, or, at any rate, to agencies other than human. At the locality above referred to, the coal outcrops along the sides of a deep gulch, and its burning is accompanied by the emission of much heat and of considerable volumes of sulphurous gases.

The unburned strata are typically of a gray or buff color, but upon the burning-out of an underlying coal seam they assume most gaudy hues of bright yellow, pink, or deep brick-red; the stratum beneath the coal is usually but little affected. Frequently a red layer may be traced from butte to butte, in each case underlain by the ash of the burned-out coal seam. With the change in color go incipient fusion and an increase in the coherence and resistance of the strata. This increased resistance has had a marked influence upon the topography, and it is common to find buttes capped with a layer of this baked material which has served to retard the progress of normal erosion.

Rocks resulting from the baking and fusion above described have been referred to by German geologists under the names *Porzellanit* and *Porzellanjaspis*[1] and have been observed by them in a number of the European coal fields. Similar materials have been observed by the writer in the Coal Measures near La Salle, Ill. The principal varieties of altered material observed in the Wyoming region are described below.

1. By far the largest part of the metamorphosed beds consists of buff, brick-red, or indian-red argillaceous material. Much of this is fissile along bedding-planes, and incloses lamellibranch shells and shows impressions of leaves in great perfection; other portions are more massive and show a somewhat conchoidal fracture; still

[1] Zirkel, *Lehrbuch der Petrographie*, Vol. III, p. 775.

other portions, especially near the slaglike masses (No. 3, below), are extensively and very irregularly fractured. The metamorphism of these rocks finds a parallel in the artificial process of the burning of bricks, and consists simply in an oxidation of the iron from the ferrous to the ferric state, and in incipient fusion which greatly increases the coherence.

2. The coal itself leaves behind a typical ash upon burning; most of this is loose and incoherent, but some parts are clinker-like.

3. Slaglike masses make up only a small proportion of the beds, but are striking because of their close resemblance to lavas. They form very irregular, dark brown or mottled, vesicular masses, and usually inclose numerous fragments of shale and sandstone. Occasionally the slag occurs as an uneven layer just above the burned-out coal bed, but in most of the localities visited by the writer it formed isolated masses which in many instances seemed to be almost surrounded by the baked clays described above. Allen[1] also describes "chimney-like" forms a few feet in diameter capping buttes because of their superior resistance. The forms of the slaglike masses, and the sharp transition to beds which have been but slightly metamorphosed, suggest that they represent channels of easy exit for the hot gases and vapors, along which the metamorphism was much more considerable than in any other portion, except immediately above the coal bed, where slags are also occasionally developed. The ropy surfaces exhibited by some of the slags show how fluid much of the material must have been.

4. The inclosing argillite near the slaglike masses has in most cases been much brecciated, and one of the characteristic types of rock is formed by the penetration of the crevices of such breccia by the slag. The process usually results in the induration of the breccia fragments to hard, flintlike masses, red, buff, or gray in color.

A microscopic examination of one of these slag veins in red argillite showed a central, relatively coarsely holocrystalline mass about one-tenth of an inch across. This was bordered on each side by a zone about one-fiftieth of an inch wide, fine-grained, prevailingly gray in color, and apparently representing the contact effect of the slag on the argillite. Outside this narrow zone the argillite shows

[1] *Ibid.*, p. 250.

a reddish tint. In passing from the reddish argillite towards the center of the vein, the contact zone shows a gradual decrease in the normal shale constituents and a development, in increasing amount and coarseness, of purplish-blue, pleochroic cordierite. Next the coarser part of the vein this mineral is present to the exclusion of all others. In this contact zone the red iron oxide of the argillite has been wholly reduced to magnetite. The central portion of the vein is a somewhat vesicular, holocrystalline mass, consisting of abundant magnetite in irregular masses, some hematite, usually lining the vesicles and following fractures, and abundant cordierite, feldspar, and pyroxene. The cordierite occurs in good-sized grains, some of which have a very irregular outline, while others show very definite crystalline forms, occurring in short prisms whose very perfect hexagonal cross-sections are the result of characteristic repeated twinning, as is shown by the optical properties. The feldspar occurs in narrow lath-shaped crystals with irregular terminations, and often with irregular lateral boundaries. No crystals were found which showed more than two twinning lamellæ. The index of refraction is slightly above that of the balsam, and about equal to that of cordierite. This character, and the low extinction angles (less than 3°), fix its composition as oligoclase. Pyroxene occurs, sometimes in grains, but mainly in long, prismatic crystals, whose length ranges from ten to almost fifty times their width. The pleochroism is moderately strong; the colors for rays vibrating parallel to the prism length range from deep green to greenish-yellow, with occasional portions of the prism which are reddish-brown; for rays vibrating perpendicular to the prism, the color is usually greenish-yellow. Cross-sections show typical pyroxene cleavage, and the extinction angles range up to 32°.

5. A small proportion of the beds are fine-grained, porous sandstone which, upon baking, assumes the brilliant colors observed in the clayey members. Microscopically the slag is seen to penetrate this porous rock so thoroughly that it is impossible to draw a sharp line between the slag and the original sandstone. The sandstone, consisting of small angular quartz grains, fine argillaceous material, and hematite in scattered grains and as a fine coating on the other minerals, passes into a glassy mass inclosing scattered quartzes and

abundant minute crystals of hematite, the latter frequently grouped in aggregates; this in turn passes into a vesicular, dark gray mass in which distinct quartz fragments are absent, the iron largely in the form of magnetite, and cordierite very extensively developed; some feldspar may perhaps be present, but could not be identified.

The complete crystallization of a vein of slag one-tenth of an inch across, and the perfect development of many of the crystals, are probably to be explained by high temperature of the rock walls when the slag flowed in, and a consequent slow cooling. In general, the physical conditions under which the metamorphism took place are similar to those in the slag furnace, and the resulting products are slaglike in appearance. The materials involved are, however, somewhat different from those of most slags. They are typical pelites, and it is not surprising that one of the minerals most abundantly developed, cordierite, should be a mineral rarely found in artificial slags, but one of the commonest minerals developed in the contact metamorphism of pelitic sediments.

THE DELAWARE LIMESTONE[1]

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HISTORICAL REVIEW

The division and correlation of the Devonian limestones of Ohio have been a subject of consideration by geologists for many years, and there have been decided differences of opinion. Recently Dr. Charles K. Swartz, of Johns Hopkins University, and the writer have studied these limestones, in the main working independently, but arriving at quite similar general conclusions. The following rather brief chronological review of the most important opinions will probably acquaint the reader with an outline of the subject under consideration.

In 1838 Professor Locke adopted the name "Cliff limestone" "for the very extensive deposit of limestone above the blue limestone"[2] (the latter limestone he described as alternating with layers of marl in southwestern Ohio, and it belongs in what is now known as the Cincinnatian series). In 1842 Dr. A. Clapp, in describing the rocks at the Falls of the Ohio and vicinity, stated that "under the name Cliff limestone is here included all the group above the blue limestone and marls of Cincinnati, to the black slate."[3] The

[1] Published by permission of Edward Orton, Jr., state geologist of Ohio.

[2] *Second Annual Report of the Geological Survey of Ohio*, p. 211.

[3] *Proceedings of the Academy of Natural Science*, Philadelphia, Vol. I, p. 178.

black slate mentioned by Dr. Clapp is now known as the New Albany black shale, which in a general sense may be regarded as the western continuation of the Ohio shale. It was, furthermore, reported that Dr. Clapp made the following correlations between divisions of the Cliff limestone and certain New York formations:

> The lower and middle portions of the Cliff limestone he conjectures to be equivalents of the Niagara limestone and Gypseous shales; the entire mass called the Cliff limestone represents therefore the Niagara limestone, Gypseous shales, water-lime, Onondaga limestone, etc., to the Marcellus shales.

It is stated by Dr. Newberry that the Corniferous limestone was first identified in Ohio by Professor Hall in 1841;[1] but in his paper entitled "Notes upon the Geology of the Western States," Professor Hall's statement is simply this: "In examining the upper part of the 'cliff limestone' I found it, so far as lithological characters are concerned, a continuation of the Helderberg group;" and the Niagara limestone is mentioned as occurring in "the vicinity of Columbus."[2] In another article, however, published the following year, Professor Hall reported the occurrence of the Corniferous limestone in the vicinity of Columbus, stating that

> a short distance to the west of that place [Columbus] the Corniferous limestone of New York appears, presenting its characteristic fossils. This mass is the upper part of the cliff limestone formation of Dr. Locke, the name by which it is generally known in Ohio.[3]

In 1847 de Verneuil stated that the Devonian system in New York

> is principally composed of schists and argillaceous sandstones, which, as we have said, are lost and disappear in the West; it thence results that in the states of Ohio, Indiana, and Kentucky it is reduced to the black schists, which represent the Genesee slate, and to a calcareous band which represents at once the Corniferous and Onondaga limestones and the Hamilton group of the state of New York.[4]

Under Dr. Newberry's direction, the Devonian limestones, which he called the Corniferous, were carefuly studied during the progress

[1] *Report of the Geological Survey of Ohio*, Vol. I, Part I (1873), p. 142.

[2] *American Journal of Science and Arts*, Vol. XLII (1842), p. 58.

[3] *Transactions of the Association of American Geologists and Naturalists* (1843), p. 273.

[4] Hall's translation in *American Journal of Science and Arts*, second series, Vol. V (1848), pp. 369, 370. The original is in the *Bulletin de la Société géologique de France*, second series, Vol. IV (1847), p. 680.

of the Second Geological Survey of Ohio, and in his first report their distribution was shown on the "Preliminary Geological Map of Ohio,"[1] together with some account of their occurrence, lithology, and fossils;[2] while the chapter on the Devonian system in the first volume of the Geological Survey of Ohio contained a more elaborate description.[3] He made two divisions of this limestone: the upper one, termed the *Sandusky limestone*, described as blue and thin-bedded, from fifteen to twenty feet thick, quarried at Sandusky and Delaware; and the lower division, called the *Columbus limestone*, well shown in the quarries near that city, and described as a very light-colored limestone often containing chert.[4] Dr. Newberry stated that the upper portion of the Sandusky limestone contained several characteristic Hamilton fossils in considerable abundance, as *Spirifer mucronatus*, *Cyrtia* [*Cyrtina*] *hamiltonensis*, etc.; and on account of the presence of these fossils he was for a long time in doubt whether the Sandusky limestone should not be considered as a representative of the Hamilton rather than of the Corniferous group; but, on gathering all the fossils of this formation, the list was found to include a much larger number of Corniferous than of Hamilton species.[5]

Dr. Newberry concluded that the limestones were to be correlated with the Corniferous of New York, while the Hamilton was restricted to a bed of marl and marly limestone which at Prout's Station, south of Sandusky, was stated to be from ten to twenty feet in thickness, containing "great numbers of Hamilton fossils, with none which are peculiar to the Corniferous." At Delaware, in central Ohio, a light-gray marl between the Black shale and Corniferous limestone was thought to probably represent the Hamilton, but it was stated that south of this locality no trace of it had yet been found.[6]

On the contrary, Professor N. H. Winchell, who described several of the counties in central and northwestern Ohio, came to the conclusion that the upper Corniferous was probably to be correlated with the Hamilton formation. Under his description of Delaware County we find the following:

[1] Geological Survey of Ohio, *Report of Progress in 1869* (1870), frontispiece.

[2] *Ibid.*, pp. 17, 18.

[3] *Report of the Geological Survey of Ohio*, Vol. I, Part I (1873), pp. 142–49.

[4] *Ibid.*, p. 143. [5] *Ibid.*, p 144. [6] *Ibid.*, p. 150.

The lithological characters of the Michigan Hamilton are the same as those of the upper Corniferous in Ohio, and it is hardly susceptible of doubt that they are stratigraphically identical.[1]

In his sections Professor Winchell used the names "Tully limestone," and "Hamilton," followed in the descriptive part by an interrogation point, and "Corniferous limestone."[2] The upper limestone is also mentioned under the name of "Delaware stone"[3] and "Delaware limestone,"[4] but apparently without the intention of considering it as a formation name. Later, however, in describing Paulding County, in the northwestern part of the state, Professor Winchell stated that close "attention was paid to the solution of the question, 'Do Hamilton fossils extend through the whole of the blue limestones?'"[5] and the conclusion was "that the beds that hold these Hamilton fossils are very near the bottom of the blue limestone."[6] Professor Winchell accepted this as sufficient proof of the correctness of his correlation with the New York formations, consequently on his "General Section of the Rocks of Paulding and Defiance Counties" appear the names "Tully limestone" and "Hamilton limestone of New York," below which are given the "Corniferous and Onondaga limestones of New York."[7] In the legend of the geological maps of Delaware, Paulding, and Defiance Counties, all by Professor Winchell, appears the name "Hamilton group,"[8] which is given a distinct area on the maps.

This correlation was opposed by Dr. Newberry, who said:

The Tully limestone? of Professor Winchell's sections is certainly Hamilton, as I have obtained from it *Tropidoleptus carinatus*, *Pterinea flabella*, *Nyassa arguta*, *Spirifera mucronata*, etc.

And regarding the Hamilton limestone of Professor Winchell he wrote as follows:

I think it will be seen that the weight of evidence is decidedly in favor of its being of Corniferous age. The cherty layers which lie between the Huron shale and the quarry-stone at Delaware are probably Hamilton, but the quarry-stone

[1] *Ibid.*, Vol. II, Part I (1874), p. 289.

[2] For example, see the section "through the Olentangy Shale and Hamilton Limestone, Five and a Half Miles below Stratford," on pp. 293, 294.

[3] *Ibid.*, pp. 293, 302. [4] *Ibid.*, p. 294. [5] *Ibid.*, pp. 341, 342.

[6] *Ibid.*, p. 343. The statements just quoted also appeared on pp. 395, 397, of the excerpt from the report on Paulding County, entitled "On the Hamilton in Ohio," published in the *American Journal of Science*, third series (1874), Vol. VII.

[7] *Ibid.*, p. 342. [8] *Ibid.*, facing pp. 272, 336, and p. 422.

itself, though containing some fossils which are common to the Hamilton and the Corniferous, has never yielded me any exclusively Hamilton fossils.[1]

In 1875 Professor Winchell read a paper "On the Parallelism of Devonian Outcrops in Michigan and Ohio" before the American Association, in which he gave a table of parallel "Devonian Outcrops in Michigan and Ohio," in which Sandusky, Delaware, Marion, and sec. 17, Defiance, Defiance County, Ohio, are correlated with the Hamilton blue limestone as exposed in the vicinity of Thunder Bay, Lake Huron, and near Charlevoix, Lake Michigan, in the northern part of the Lower Peninsula.[2]

Dr. Newberry's objection was restated in the succeeding state report under the "Review of the Geological Structure of Ohio," where he expressed this opinion:

> In regard to the position of the Sandusky limestone, it must be said that the weight of evidence is in favor of retaining it in the Corniferous. . . . . There is even in New York much in common between the fossils of the two groups, and all the fossils which Professor Winchell relies upon as criteria for distinguishing the Hamilton from the Corniferous, are found in both; hence their presence in the Sandusky limestone is no proof of its Hamilton age. It should also be said that quite a number of fossils are found in the Sandusky limestone which are regarded as characteristic of the Corniferous.[3]

This volume contains Dr. Orton's report on the geology of Franklin County, in central Ohio, in which he followed Dr. Newberry in correlating all of the Devonian limestone with the Corniferous. The upper division, however, of thirty-two feet of blue limestone he states is, "from its occurrence at Delaware, and the extensive use made of it at that point, well named the *Delaware limestone;*"[4] and this name was used in place of Newberry's older one of "Sandusky limestone." For the lower division Dr. Orton retained the name "Columbus limestone," and described a six-inch stratum named the "bone-bed" containing large numbers of the teeth, plates, and

[1] *Ibid.*, footnote, p. 290. For similar statements see Dr. Newberry's criticism of Professor Winchell's geological classification of Paulding County (footnote, pp. 337, 338); and Dr. Newberry's description of the Corniferous limestone of Erie County (pp. 191, 192).

[2] *Proceedings of the American Association for the Advancement of Science*, Vol. XXIV (1876), Part II, p. 59.

[3] *Loc. cit.*, Vol. III, Part I (1878), p. 11.

[4] *Ibid.*, p. 606.

bones of fishes, which occurs at the top of the Columbus and separates it from the Delaware limestone.[1]

In discussing the correlation used by Professor Winchell in his report on Delaware County, Dr. Orton said:

> The Columbus and Delaware limestones probably cover the age in which the Corniferous limestone, and the Hamilton group, in part, of New York were forming; but there seems no warrant whatever for identifying the subdivisions of our scale with the subdivisions recognized five hundred or a thousand miles away.[2]

In 1877 Professor Hall visited the Falls of the Ohio, near Louisville, and correlated the hydraulic and encrinal limestones, which are the higher limestones of the section, with the Hamilton group of New York, and said that "in the state of Ohio similar conditions may be inferred, from the fact that certain species of known Hamilton fossils are published in the Ohio Geological Reports as from the Corniferous group."[3]

In 1878 Professor Whitfield visited Franklin County, and on the banks of the Scioto River, six miles northwest of Columbus, made the most important discovery relating to the classification of the Devonian limestones that had been made in central Ohio. In a bed of dark-brown, bituminous shale, in the lower part of the Delaware limestone, flattened specimens of *Liorhynchus limitaris* (Van.), *Discina minuta* Hall, and *Lingula manni* Hall were found, the two former being strictly characteristic species of the Marcellus shale of New York. On the following day the same shale was found farther north, nearly opposite Dublin, containing *Liorhynchus limitaris* (Van.) and *Discina lodensis* (Van.). This shale was reported only a few feet above the "bone-bed," and Professor Whitfield stated: "I have no hesitation in pronouncing [it] the equivalent of the MARCELLUS SHALE of New York."[4] This discovery seemed to confirm Professor Winchell's opinion that the Delaware limestone of Delaware County represented the Hamilton formation of New York.

[1] See *Ibid.*, pp. 605, 606, 610. [2] *Ibid.*, p. 634.

[3] *Transactions of the Albany Institute*, Vol. IX (1879), p. 179. The same statement was published in *Palæontology of New York*, Vol. V, Part II, text (1879), pp. 146, 147.

[4] *Proceedings of the American Association for the Advancement of Science*, Vol. XXVIII (1880), pp. 297, 298.

Professor Whitfield published later a list of the fossils found in these shales, together with a description of two new species, under the title of "Species from the Marcellus Shales."[1] A more complete account of their stratigraphy was also published under the title of "Note on the Marcellus Shale and Other Members of the Hamilton Group in Ohio, as Determined from Palæontological Evidence."[2] In this article Professor Whitfield positively identified the shales as of Marcellus age, stating that

> only a few feet above the "bone-bed" occurs the dark-brown shale in question, with the peculiar fossils, which I have no hesitation in pronouncing the equivalent of the Marcellus shales of New York. Admitting this—and there certainly appears to be no alternative—the rocks found above this limit should represent the Hamilton group of the New York system.[3]

In the Ohio report Professor Whitfield stated that in August, 1879, he

> read a notice of the occurrence in Ohio of rocks representing the Marcellus shales of New York . . . . in which it was shown that a considerable thickness of the limestones previously recognized as "Corniferous" in Ohio, were above the horizon of the beds which I had recognized, from palæontological and lithological evidence, as of the age of the Marcellus shale, and would be of necessity equivalents of the Hamilton group.[4]

Finally, Professor Whitfield published descriptions of several "species from the limestones above the 'bone-bed,' in the vicinity of Columbus, Ohio, and not known to occur below that horizon," which included such well-known Hamilton species as *Spirifer ziczac* Hall, *Pterinea flabella* (Con.) Hall, *Nyassa arguta* H. & W., and *Grammysia bisulcata* (Con.) H. & W.[5]

Dr. Orton, in describing the geological scale of Ohio in the volume on petroleum and natural gas, changed the name of the formation from the "Corniferous" to the "Upper Helderberg limestone," and assigned the following reason:

[1] *Annals of the New York Academy of Sciences*, Vol. II (1883), pp. 212–15. Descriptions of all the species were published in the *Report of the Geological Survey of Ohio*, Vol. VII (1893 [1895]), pp. 441–47.

[2] *Annals of the New York Academy of Sciences*, Vol. II (1883), pp. 233–41. This article, with additions, was republished in *Report of the Geological Survey of Ohio*, Vol. VII, pp. 432–41.

[3] *Ibid.*, p. 235, and *Report of the Geological Survey of Ohio*, Vol. VII, p. 433.

[4] *Report of the Geological Survey of Ohio*, Vol. VII, p. 434, footnote.

[5] *Ibid.*, pp. 447–52.

All of the limestone of the Devonian age in Ohio has been referred by Newberry, to the Corniferous limestone, and this term is in general use at the present time. It may be questioned whether it is wise to break in upon this here, but inasmuch as several geologists hold that the Devonian limestone of Ohio covers more than the single epoch known as Corniferous in New York, a more comprehensive term, viz., the Upper Helderberg limestone, is counted preferable. A twofold division of the series is possible and proper in Ohio, the division being based on both lithology and fossils. The divisions are known as Lower and Upper Corniferous, or as Columbus and Delaware limestones. For the upper division the term Sandusky limestone is sometimes used.[1]

On the "Geological Map of Ohio," accompanying this report, the "key to formations" mentions the Upper Helderberg limestone, Marcellus shale, Hamilton limestone, and Hamilton shale, which are all represented by one color on the map.

The substitution of the name "Upper Helderberg limestone" for "Corniferous limestone" did not meet any of the objections raised by Winchell, Hall, and Whitfield to the Newberry classification of the Devonian limestones of Ohio, because, so far as the later formations are concerned, it is not a more comprehensive term than the "Corniferous limestone," and in its classic locality, the Helderbergs of eastern New York, has never been applied to rocks above the base of the Marcellus shale. The name "Helderberg division" was proposed by Vanuxem in 1842, and included all the formations occurring between the top of the Niagara limestone and the base of the Marcellus shale.[2] In the following year Mather's report appeared, in which the rocks of the Helderberg mountains are described, and it is stated that, on account of their excellent development at this locality, "forming a natural group, strongly marked in their lithological and paleontological characters from the strata lying above and below them, the term of *Helderberg division* is used to designate them."[3] In the northern Helderbergs nearly all of the subjacent Ontario division is absent, and Mather's Helderberg division included all the formations found at this locality between the top of the Hudson

[1] *Ibid.*, Vol. VI (1888), pp. 20, 21. "Upper Helderberg limestone" is also used by Dr. Orton for the formation in his article on "The Trenton Limestone as a Source of Petroleum and Inflammable Gas in Ohio and Indiana" (*Eighth Annual Report of the United States Geological Survey*, Part II (1889), p. 568.)

[2] *Geology of New York*, Part III (1842), pp. 13, 15, 16.

[3] *Ibid.*, Part I (1843), p. 325.

(Lorraine beds) and the base of the Marcellus shale. Later studies, however, have shown that the "Pyritous slates," forming the basal member of his Helderberg division, are probably of Salina age;[1] while Mather's succeeding division—the Water limestone—which he gave as composed of two members, the Water limestone and Tentaculite limestone, now called the Rondout waterlime and the Manlius limestone, is also separated from the Helderbergian series as defined by Dr. John M. Clarke, and put in the subjacent Cayugan series.[2]

Professor Hall in 1859 divided the rocks of the Helderberg mountains into the Lower and Upper Helderberg groups, which were separated by the Oriskany sandstone and Cauda-galli grit.[3] The Upper Helderberg group was composed of the Schoharie grit and Onondaga and Corniferous limestones; or, in other words, it included the rocks between the top of the Cauda-galli grit (now called Esopus grit) and the base of the Marcellus shale.

Regarding Whitfield's discovery Dr. Orton said:

> At a few points in central Ohio the upper division [Delaware limestone] has been found in a shaly state and carrying characteristic fossils of the Marcellus slate. This fact was first noticed in its true significance by Whitfield.[4]

The name "Upper Helderberg limestone" was used by Dr. Orton for the formation, and the same reasons for its use were published in his first annual and final report of the Geological Survey of Ohio;[5] but in his last review of the "Geological Column of Ohio" he returned to the earlier name of "Corniferous limestone."[6]

In the last edition of Dana's *Manual* the Delaware limestone is apparently considered as of Hamilton age, for in giving the distribution of its beds it is stated that "they appear also in Ohio, as

[1] Hartnagel, New York State Museum, *Bulletin No. 69* ("Report of the State Paleontologist," 1902), 1903, pp. 1116, 1170, 1171.

[2] New York State Museum, *Handbook No. 19* (1903), pp. 8, 9, 14.

[3] *Palæontology of New York*, Vol. III, Part I (1859), p. 97.

[4] *Report of the Geological Survey of Ohio*, Vol. VI (1888), p. 22.

[5] *First Annual Report of the Geological Survey of Ohio* (1890), pp. 24–26; *Report of the Geological Survey of Ohio*, Vol. VII (1893 [1895]), pp. 18, 19.

[6] *Nineteenth Annual Report of the United States Geological Survey*, Part IV (1899), pp. 638, 646, 682.

twenty-five feet of impure bluish limestone,"[1] although under the account of the Corniferous limestone the Delaware is mentioned as the upper division in Ohio.[2]

In 1898 Professor John A. Bownocker published a paper on "The Paleontology and Stratigraphy of the Corniferous Rocks of Ohio," in which is given a number of sections of the limestone as shown in various quarries, accompanied by lists of fossils collected at twelve different localities in the state. The Corniferous limestone of this article includes both the Columbus and Delaware divisions, and at the close of the discussion on the "Relation of the Fauna above the Bone-Bed to that Below" it is stated:

> It appears, therefore, that the difference between the faunas above and below the bone-bed in the central Ohio area is not great, that this difference is most conspicuous at Delaware and diminishes to the north, being least at Sandusky.[3]

Dr. Edward M. Kindle carefully studied the Devonian limestone of southern Indiana and northern Kentucky, and stated that near the Ohio River it "is readily separated into two divisions, which are easily distinguished from each other both by lithological and paleontological characters."[4] The lower division he named the "Jeffersonville limestone" and the upper one the "Sellersburg beds." Kindle's *Bulletin* was based on a thorough study of the fossils, and in discussing the "Correlation of Faunas" he stated:

> The Corniferous fauna of New York suffers no very important modifications in its western extension. The large number of species common to the faunas of the Corniferous limestone of New York and the Jeffersonville limestone, especially among the corals, leaves no doubt as to the equivalence of the two faunas. . . . . In southern Indiana we find in the Sellersburg beds a fauna containing many of the most characteristic species of the Hamilton of New York. . . . . This fauna is not mingled with the Corniferous, as was once supposed, but occurs above that fauna in the Sellersburg beds. The presence in it of such characteristic Hamilton fossils as those mentioned seems to leave no doubt of its equivalence to the New York Hamilton.[5]

It will be noticed that this conclusion regarding the correlation of these limestones is in perfect harmony with the later views of Professor Hall.

[1] *Manual of Geology*, 4th ed. (1895), p. 592. [2] *Ibid.*, p. 581.

[3] *Bulletin of the Scientific Laboratories of Denison University*, Vol. XI, p. 39.

[4] *Bulletin of American Paleontology*, No. 12 (1899), p. 8. [5] *Ibid.*, p. 110.

A further elaboration of this work by Dr. Kindle was later published in an Indiana *Report* which contained an account of the Devonian stratigraphy of Indiana, together with descriptions and figures of its fossils. Dr. Kindle's conclusions regarding the correlation of Devonian limestones of Indiana are stated as follows in this report:

> The problem of the correlation of the Devonian limestones with the New York scale is much more difficult for some parts of the Indiana province than for others. In the vicinity of the Falls of the Ohio we find two quite distinct and well-marked faunas. These are the *Spirifer granulosus* and the *Spirifer acuminatus* faunas, and represent respectively the Hamilton and Corniferous faunas of New York. Near the Falls of the Ohio, the Sellersburg beds, and the Jeffersonville limestone, which carry these faunas, are sharply differentiated lithologically, the Jeffersonville limestone being a nearly pure limestone, and representing clear water conditions during its deposition, while the Sellersburg beds are composed of an impure argillaceous limestone. In the northern part of the southern Indiana area these two formations cease to be sharply differentiated lithologically, and merge into each other in a limestone which is neither so pure as the Jeffersonville limestone nor so argillaceous as the Sellersburg beds near the Falls. Associated with the loss of individuality of these two formations occurs a mingling of their two faunas which renders them indistinguishable as separate faunas.
>
> In the Wabash area the faunas of the Devonian limestone are even more distinct than that at the Falls of the Ohio. In the lower one *Spirifer acuminatus* is an abundant fossil, and the fauna does not differ greatly from that in the Jeffersonville limestone at the Falls of the Ohio. The upper fauna is a distinctly Hamilton fauna, but entirely different from the Hamilton fauna of southern Indiana.[1]

At an early date Hamilton fossils were identified by Professor Alexander Winchell from the northern part of the Lower Peninsula of Michigan and the rocks referred to the Hamilton group. In 1870 he named it the "Little Traverse group,"[2] which in 1895 was shortened by Dr. Lane to the "Traverse group."[3] The southern part of the state is so heavily mantled by drift that formerly it was not known whether the formation occurred there or not; but later study of well sections has shown its presence with a thickness of about eighty feet. On a recent geological map of the Lower Peninsula the formation is shown crossing Monroe and Lenawee Counties

[1] *Twenty-fifth Annual Report of the Department of Geology and Natural Resources of Indiana* (1900), p. 570.

[2] *Report of Progress*, State Geological Survey of Michigan, p. 28.

[3] *Geological Survey of Michigan*, Vol. V, Part II, p. 24.

in the southeastern corner of the peninsula,[1] and entering Ohio at about the locality where the Hamilton or upper part of the Corniferous has been represented on the state maps. Since then Professor Sherzer has given a more detailed account of the "Traverse (Hamilton) group" of Monroe County, Mich., in his geological report of that county.[2]

In 1902 Professor Weller published a paper on "The Composition, Origin, and Relationships of the Corniferous Fauna in the Appalachian Province of North America," in which he stated that "in Ohio the fauna occurs in the Columbus limestone."[3] The Delaware limestone was not mentioned, and apparently he did not consider its fauna as that of the Corniferous. Professor Claypole, in his account of "The Devonian Era in the Ohio Basin," stated near the close of the section devoted to "The Corniferous Limestone," that

> what has already been said must not be referred to the whole mass of strata which have usually been classed under the name Corniferous in Ohio geology, but only to that part lying below the bone-bed and to the bone-bed itself.[4]

The division succeeding the bone-bed Professor Claypole called "the Corniferous-Hamilton period," and stated that "the period was, in Ohio, evidently one of transition."[5] His correlation of the several members of the two periods is shown in the following table:

Shale at Prout's Station	Hamilton
Blue limestone, thin-bedded	Corniferous-Hamilton
Dublin blue [brown] shale	Marcellus
Bone-bed	Corniferous
Gray and buff limestones	Corniferous[6]

The same year Professor Schuchert, in his paper on "The Faunal Provinces of the American Middle Devonic," apparently accepted Whitfield's correlation of the Devonian limestones of central Ohio.[7]

Finally, in New York state, which is the standard one for the correlation of the American Devonian, the geographic name of "Onondaga limestone" has been adopted in place of "Corniferous

[1] *Water-Supply and Irrigation Papers*, U. S. Geological Survey, No. 30 (1899), Plate VI.

[2] *Geological Survey of Michigan*, Vol. VII, Part I (1900), pp. 31–35.

[3] *Journal of Geology*, Vol. X, p. 424.

[4] *American Geologist*, Vol. XXXII (1903), p. 31.

[5] *Ibid.*, p. 35. [6] *Ibid.*, p. 35. [7] *Ibid.*, p. 148.

limestone," which was based upon a lithologic character of the formation.[1]

DESCRIPTION OF THE DELAWARE LIMESTONE

The principal object of this paper is to consider the upper formation of the Ohio Devonian limestones, and decide upon the name which shall be applied to it. The name "Delaware limestone" was first definitely applied to this division as a formation name by Dr. Orton, and published in 1878. He briefly described it as "the blue limestone, thirty-two feet in thickness, which is, from its occurrence at Delaware, and the extensive use made of it at that point, well named the *Delaware limestone.*"[2] So far as the writer is aware, the term "Delaware limestone," when published by Dr. Orton in 1878, was available for the name of a geological formation, and was definitely described in Franklin County, so that there is no doubt regarding its limits. Since 1878 the name "Delaware," forming all or part of the designation, has been applied to at least three other geological divisions; but these names, if considered identical, will not replace Dr. Orton's "Delaware limestone," but will be abandoned because of preoccupation. The names are as follows: (1) *Delaware river beds*, applied by Dr. I. C. White to an upper Devonian terrane of northeastern Pennsylvania;[3] (2) the identical term, so far as the geographical part of the name is concerned—*Delaware stage*—was given by Professor Calvin to the lower part of the Niagaran series in eastern Iowa;[4] and (3) the name "Delaware mountain formation" has very recently been given by Mr. George B. Richardson to a Permian formation of southwestern Texas.[5]

Although Dr. Orton's name for this formation apparently referred to the exposures in the vicinity of Delaware, still the section giving its entire thickness which he described, and which may therefore be considered his type section, is in the Scioto valley, about one

[1] Clarke and Schuchert, *Science*, N. S., Vol. X (1899), p. 876; Clarke, N. Y. State Museum, *Handbook No. 19* (1903), pp. 8, 21, 22.

[2] *Report of the Geological Survey of Ohio*, Vol. III, Part I, p. 606.

[3] *Second Geological Survey of Pennsylvania; G*[6] (1882), p. 99.

[4] *Iowa Geological Survey*, Vol. V (1896), pp. 49, 50.

[5] University of Texas Mineralogical Survey, *Bulletin No. 9* (November, 1904), p. 38.

mile north of Dublin, in the northern part of Franklin County.[1] This region may, therefore, be considered as typical as that in the vicinity of Delaware, and has the advantage of showing clearly in several sections both the upper and lower limits of the formation. It will be interesting, therefore, to describe somewhat carefully a section to the south and another one to the north of the one described by Dr. Orton.

Fig. 1.—Shale zone forming the lower part of the Delaware formation, as shown on Slate Run. Its top is indicated by the hammer.

SLATE RUN SECTION

In Perry Township, on the eastern side of the Scioto River, three and one-half miles north of Marble Cliff, is a locality known as Slate Run Hollow, on the farm of Mr. George Matthews. The run is one and one-half miles north of Fishinger's bridge, and about five and one-half miles in a direct line northwest of the Ohio State University, and in the lower part of the stream is the pond of the Columbus Fish-

[1] Dr. Orton named it the "section of Corniferous limestone near Corbin's mill Perry Township," Vol. III, p. 604.

ing Club. Formerly the upper part of the Columbus limestone was fairly well shown in the bluff of the Scioto River for some distance below this locality, while Slate Run affords a good section of the Delaware limestone and the overlying Olentangy shale. At this locality Whitfield first noticed the brownish shales containing a Marcellus fauna, although in the description it is not located more definitely than "six miles northwest of Columbus." A section was furnished by Dr. Orton, which was published in Whitfield's paper.[1]

No.		Thickness (Feet)	Total Thickness (Feet)
13.	*Ohio shale.*—On the northwest bank, immediately above the outcrop of Olentangy shale, is about 6 feet of the typical black, thin, arenaceous shale of this formation. The line of contact is sharp between these two shales. Farther up the stream, near the fence, the top of the Olentangy shale is near water-level, above which is about 11½ feet of the Ohio shale. A little farther up the run, and above the fence, are a number of concretions of various sizes imbedded in the Ohio shale.	11½±	107
12.	*Olentangy shale.*—Bluish or greenish to drab argillaceous shale, with the lithological appearance of typical exposures of Olentangy shale in Delaware County. One thin layer of brownish shale occurs at about the middle of the cliff, and two layers near its base. There are also thin layers of impure limestone, especially in the lower part of the formation, one of which, about 6 feet above its base, is 5½ inches in thickness. On Dr. Orton's section the Olentangy shale is given as 15 feet in thickness,[2] but this is obviously an underestimate.	22⅔	95½–
11.	Top of *Delaware limestone.*—A rather thin-bedded bluish-gray limestone, with occasional layers of chert, which extends to the top of the cascade. It may also be seen on the steep southeast bank farther down the stream, which is the best place for measuring its thickness.	13+	72¾

[1] *Proceedings of the American Association for the Advancement of Science*, Vol. XXVIII (1880), p. 298.

[2] *Ibid.*, p. 298.

No.		Thickness (Feet)	Total Thickness (Feet)
10.	Brownish-gray thin-bedded limestone, alternating with layers of chert, shown to best advantage on the southeast bank, a little above the contorted layer in the bed of the stream. This zone is conspicuous in the glens farther north, in the southern part of Delaware County.	$6\frac{3}{4}\pm$	$59\frac{3}{4}$
9.	Rather heavy-bedded grayish to brownish limestone.	$2\frac{1}{3}$	53
8.	Zone of contorted thin limestone and chert shown in the bed of the run and on its banks farther down the stream. This corresponds to the contorted stratum noted by Professor Winchell in sections of this limestone in the southern part of Delaware County.[1]	$2\frac{2}{3}$	$50\frac{2}{3}$
7.	At the base of the limestone, directly on top of the shale zone, is a thicker layer of chert, followed by layers of brownish limestone $2\frac{1}{2}$ inches or more in thickness. The measurements for this zone vary from 1 foot 6 inches to 2 feet.	$1\frac{1}{2}+$	48
6.	Brown, bituminous shales weathering to a light gray or ash color. The layers are even and thin, rather arenaceous in places, interrupted by several layers of chert, and contain a considerable number of fossils, especially in the lower part, although the number of species is small. The measurements of this zone vary from 5 feet 10 inches to 6 feet 6 inches, and it is well exposed on the southeastern bank of the run, where it has the general appearance of a bank of shale. It is shown in Fig. 1, the top of the zone being indicated by the hammer. This is the shale which Whitfield correlated with the Marcellus of New York, and it forms the base of the Delaware formation in this section, which has a thickness of $32\frac{1}{2}$ feet.	$6\pm$	$46\frac{1}{2}$
5.	*Columbus limestone.*—In the upper part of the top stratum are numerous fragments of the teeth, plates, and bones of fishes, the *bone-bed* which is well shown on the southeastern bank of the run a little above the fall. In the quarry wall, 5+ inches below its top, *Spirifer acuminatus* (Con.) Hall occurs, and 7 feet 3 inches lower is the "smooth layer," which is found from 9 feet 2 inches to 10 feet 5 inches below the top of the Columbus limestone in all of the sections in the Columbus region. In the upper Casparis quarry there are apparently two such layers, the upper one 9 feet 7 inches, and the lower one 10 feet 6 inches, below the top of the formation.	$7\frac{3}{4}+$	$40\frac{1}{2}-$

[1] *Geological Survey of Ohio*, Vol. II, Part I (1874), p. 289, No. 22.

No.		Thickness (Feet)	Total Thickness (Feet)
4.	From the "smooth layer" to the level of the Fishing Club pond, which is mainly rather dark gray, fairly massive limestone.	10⅓	32⅔
3.	Mostly covered from the level of the pond to the top of the cliff just below the highway bridge.	9⅓	22⅓
2.	Zone of light gray, very fossiliferous limestone, at the base of which are numerous specimens of *Spirifer gregarius* Clapp.	3⅔	13
1.	Rather dark gray, fairly massive limestone to the base of the exposure, which formerly was about 7 feet above the level of the Scioto River. Zones 1 to 5, inclusive, are all in the Columbus limestone.	9⅓	9⅓

In the brown shales of No. 6 of the above section the writer has collected the following species:

1. *Liorhynchus limitare* (Van.) Hall.
2. *Orbiculoidea lodiensis* (Van.) Hall and Clarke.
3. *Orbiculoidea minuta* (Hall) Beecher.
4. *Martinia maia* (Billings) Schuchert.
5. *Tentaculites scalariformis* Hall.
6. *Crinoid* stem (small one).

At this locality Whitfield found:

1. *Liorhynchus limitare* (Van.) Hall.
2. *Orbiculoidea minuta* (Hall) Beecher.
3. *Lingula manni* Hall.[1]

The range of the above species in New York is as follows: *Liorhynchus limitare* (Van.) Hall is, perhaps, the most characteristic species of the Marcellus shale; *Orbiculoidea lodiensis* (Van.) Hall occurs in the Hamilton beds and Genesee shale; *O. minuta* (Hall) Beecher, Marcellus shale; *Martinia maia* (Billings) Schuchert is reported in the Onondaga limestone of Ontario; *Lingula manni* Hall, in the Delaware limestone of Ohio; and *Tentaculites scalariformis* Hall, in the Onondaga limestone of New York. Of these species *Liorhynchus limitare* is abundant, occurring more frequently than any other; *Orbiculoidea lodiensis* and *O. minuta* are common, and the remaining ones rare. It is to be noted that the abundant species

[1] *Proceedings of the American Association for the Advancement of Science*, Vol. XXVIII, p. 297.

of this zone occur in the Marcellus shale and later Devonian formations of New York, instead of the Onondaga limestone, and therefore supports Whitfield's conclusion that it is the "equivalent of the Marcellus shale of New York."[1]

DEEP RUN SECTION

In the southern part of Delaware County a number of small streams entering the Olentangy River afford good sections of a part or all of the Delaware limestone. One of the best of these is the small stream known as Deep Run, on the Matthews farm on the eastern side of the river, which enters the river at the ford opposite the Armstrong farm. The stream is rather more than three-fourths of a mile north of the Powell road and bridge, about one-half mile south of the Orange road and bridge, and may be readily reached from Stop No. 42 on the Columbus, Delaware & Marion Electric Railway.

No.		Thickness (Feet)	Total Thickness (Feet)
10.	*Ohio shale.*—Mainly black, thin, somewhat gritty shale, but there are thin layers of greenish or mottled shale. The barometer indicates that 95 feet is shown, in the lower 40 feet of which are numerous concretions, some of which are of large size.	95	175½+
9.	*Olentangy shale.*—Mainly greenish shale, the top of which is sharply shown in a small fall in the stream, and a little below in a steep bank of shale on its northern side, where 10½ feet of Olentangy shale is shown. Calcareous concretions occur in the upper part of this shale, which are well shown in the bank just mentioned, where one layer occurs about 3½ feet below its top, another 7½ feet below, and a third 9 feet below, of impure calcareous material which nearly forms a layer. These concretions contain plenty of marcasite or iron pyrites. There is also a brownish layer of shale a foot or so above the lower line of concretions. The measurement is by hand level from the top of the limestone over the covered valley and up the bank to the northeast to the base of the Ohio shale, as shown in a small lateral ravine; but there is a heavy dip in the same direction, so that the measurement of 25 feet is less than the true thickness, probably to the extent of 5 feet.	25+	80½+

[1] *Ibid*, p. 298.

No.		Thickness (Feet)	Total Thickness (Feet)
8.	*Delaware limestone.*—Upper portion thinner-bedded than the lower part of this zone, impure dark colored limestone containing considerable chert. Lower part is fairly massive, impure bluish-gray limestone weathering to a brownish color and containing nodules of chert. This zone is shown on the southern bank of the stream at the upper end of the gorge, where the measurement was made. This zone is not especially fossiliferous, and at the base is a shaly parting.	9½	55½
7.	Layers of brownish limestone, alternating with thick layers of chert, all of which are undulating, giving a contorted appearance to the entire zone.	4½	46
6.	Brownish, fairly thick-bedded limestone, with chert partings, in which is a small abandoned quarry on the northern bank of the run. Thickness, about 6 feet 5 inches.	6½–	41½–
5.	Heavy layer of quarry stone at base of quarry.	1½	35
4.	Shaly to thin-bedded brownish limestone, with layers of chert.	8⅚	33½
3.	Brownish, massive bituminous limestone, which is fossiliferous. Base of the Delaware limestone, but there is no shale zone as in the sections farther south. This gives a thickness of nearly 35½ feet for the Delaware limestone in this glen, which is about 5 feet more than in the Franklin County sections.	4⅔	24⅔
2.	*Columbus limestone.*—Light gray, massive, fossiliferous limestone. The bone-bed is fairly well defined here at the top of this formation, but the change of color from the brownish Delaware to the light gray Columbus is conspicuous. The smooth layer was noted by Mr. G. F. Lamb at a distance of 10 feet below the top of the Columbus.	18½	20
1.	Covered interval to level of Olentangy River.	1½	1½

Mr. G. F. Lamb recently measured this section and made it twenty-one and one-half feet from the river level to the top of the Columbus limestone. The rocks forming the Delaware limestone in this section are quite sharply folded, so that some care is required in obtaining an accurate measurement of their thickness, while at the lower end of the Delaware part of the gorge is a faulted block on the southern side. Zone No. 4 of the above section, showing the alternation of shaly to thin-bedded limestone with layers of chert,

is well exposed about one and one-half miles farther up the river and about one-half mile south of the Lewis Center road, in a run on the farm of Mrs. Amelia Case, a view of which is given in Fig. 2.

Professor Winchell in the Delaware County report described an exposure in the southern part of the county, under the heading of a "Section through the Olentangy Shale and Hamilton Limestone, Five and a Half Miles below Stratford."[1] Professor Winchell

FIG. 2.—View of the zone of alternating limestone and chert in the lower Delaware on the farm of Mrs. Amelia Case.

described a small quarry not far below the ravine of his section, and such an abandoned quarry and river bluff occur a few rods south of Deep Run; so it is believed that the localities are identical. Professor Winchell gave the thickness of the Olentangy shale as thirty feet, which is probably not greater than its true thickness in this glen, and the combined thickness of what he called the Tully limestone (?) and Hamilton (?) (our Delaware limestone) as thirty-seven feet, with seventeen feet of Corniferous (Columbus) limestone below.

[1] *Report of the Geological Survey of Ohio*, Vol. II, Part I (1874), p. 293.

The Tully limestone is a formation succeeding the Hamilton beds of central New York, but as a limestone it does not extend west of Canandaigua Lake. Zone 8 of my section represents Nos. 3 and 4 of Professor Winchell's section, which he called the "Tully limestone (?)." The beds are impure limestone, differing to some extent from the middle and lower Delaware, but not particularly resembling the Tully limestone; and to the writer there does not appear to be sufficient proof, from either the lithological or paleontological standpoint, to warrant the correlation of this zone with the Tully limestone of New York.

THE SANDUSKY LIMESTONE

In 1873 Dr. Newberry briefly described the upper division of the Devonian limestones of Ohio, which he called the "Corniferous," and named it the "Sandusky limestone." His description was as follows:

> In the northern and middle portions of the state the Corniferous limestone shows two well-marked and several less conspicuous subdivisions. Of these the uppermost is a blue, thin-bedded limestone, from fifteen to twenty feet in thickness, and is the rock quarried at Sandusky and Delaware. This I have designated as the *Sandusky limestone*.[1]

Dr. Newberry did not mention any particular locality at Sandusky as typical for the Sandusky limestone, but conversation with Mr. Charles Schoepfle, who has been in the quarrying business for fifty-two years in that city, and who distinctly remembers Dr. Newberry and accompanied him to some extent in his investigation of the quarries, has acquainted the writer with the exposures that were then available. At that time, in 1869 and the early seventies, the principal quarries in Sandusky were those on Hancock Street, in the vicinity of the present quarry of Charles Schoepfle & Son. The present large quarries south of the Soldiers' Home and Sandusky—Wagner Stone Co. and the Hartman quarry—were opened much later than the Hancock Street quarries. The oldest of the quarries south of Sandusky is the Wagner, which, according to Mr. Alex. M. Wagner, was first opened in a primitive manner about twenty-five years ago, the Soldiers' Home quarry about sixteen, and Hartman's nine years

[1] *Ibid.*, Vol. I, Part I, p. 143.

ago. Mr. Schoepfle, however, stated that the first one opened on the Soldiers' Home grounds was the one on Hancock Street in 1877.

LAKE SHORE AND MICHIGAN SOUTHERN RAILROAD QUARRY

So far as known to the writer, none of the quarries in Sandusky or its immediate vicinity affords an excellent continuous section of the Columbus and its overlying limestone. Such an exposure of their contact, however, is to be found in the Lake Shore & Michigan Southern Railroad quarry, two and three-quarters miles southwest of the Lake Shore station in Sandusky, and two and one-half miles northeast of Castalia, in Margaretta Township; and for this reason it will be first described. According to Mr. Wagner, it was worked as much as twenty-five years ago, and my attention was first called to it by Dr. Charles K. Swartz, of Johns Hopkins University, who stated that the contact of the Columbus and Delaware limestones was to be seen in its western part. The upper part of the following section was obtained near the western end of the southern wall of the quarry, and the lower portion near its angle in direction:

No.		Thickness (Feet)	Total Thickness (Feet)
10.	Brownish-gray limestone, which contains fossils as *Leptæna rhomboidalis* (Wilckens) and *Glyptodesma erectum* Hall.	1+	19¼
9.	Chert zone.	⅛	18¼
8.	Brownish-gray limestone, but not encrinal, in which *Leptæna rhomboidalis* (Wilckens), *Chonetes mucronatus* Hall, *Glyptodesma erectum* Hall, and *Grammysia bisulcata* (Con.) were found.	¾	18 1/12
7.	Chert zone.	¼	17½
6.	Crinoidal limestone of brownish-gray color, which separates into several layers. *Leptæna rhomboidalis* (Wilckens) occurs, but the zone does not contain many fossils, with the exception of the Crinoid segments, which form an appreciable part of the rock. Shale parting at the base.	4⅜	17¼
5.	Compact massive limestone, with crinoidal band near its center; but in other parts of the quarry the entire zone is more of an encrinal limestone. The thickness varies from 1 foot 9 inches to 1 foot 10 inches.	1¾	12¼

No.		Thickness (Feet)	Total Thickness (Feet)
4.	Layer of brownish, calcareous shale, weathering to an ash color, in which part of a fish tooth was found. Lithologically very similar to the shale at the base of the Delaware limestone in Franklin County.	$\frac{1}{4}$	$10\frac{1}{2}$
3.	In upper part of layer, fragments of teeth and fish bones similar to bone-bed at top of Columbus limestone in central Ohio. Lower it is more crystalline in structure, grayish in color, and contains cup corals and other fossils. This contact is shown in Fig. 3, where the collecting bag rests on top of this zone, and the hammer indicates the superjacent shale of No. 4.	$2\frac{1}{2}$	$10\frac{1}{4}$
2.	At this horizon generally a conspicuous zone of *Eridophyllum verneuilanum* E. & H. from 4 to 6 inches in thickness.	$\frac{1}{2}$	$8\frac{1}{6}$
1.	Exposure at angle of southern wall, which extends about as low as in any part of the quarry. This limestone is rather bluish-gray, weathering to a lighter color, somewhat crystalline and fossiliferous. At the angle all of the rock belongs in the Columbus limestone, but there is quite a heavy dip to the west, so that farther along the wall the Delaware limestone is shown as described in the upper part of this section.	$7\frac{2}{3}$	$7\frac{2}{3}$

The brownish limestone alternating with layers of chert, which form the upper part of this section, closely agrees in lithologic characters with the second zone of the Delaware limestone, which succeeds the brownish shales or limestones in the sections in the northern part of Franklin and southern part of Delaware Counties. In the upper part of No. 3 of the above section are a considerable number of fragments of teeth and bones of fish, forming something of a bone-bed, which is overlain by a three-inch layer of brownish shale. Two feet one inch below the top of the bone-bed is a conspicuous *Eridophyllum* zone, similar to the one occurring in the exposures of the Columbus limestone, near Columbus, from two feet eight inches to three feet below its top. It therefore appears to the writer better to draw the line of division between the Columbus and Delaware limestones in this section at the top of No. 3, and refer the five feet ten inches of rock between it and the base of the lowest chert zone, or No. 7, to the Delaware limestone. This will agree lithologically with the sections in the southern part of Delaware and northern part

of Franklin Counties, where there is from four feet eight inches to six feet of limestone or shale intervening between the base of the owest conspicuous chert layer and the bone-bed at the top of the Columbus limestone. On the other hand, there is evidence favoring the reference of the crinoidal layers to the Columbus limestone which is the view taken by Dr. Swartz. He has written me as follows regarding this point:

> I became convinced that the best ground of separation is the faunal break, and it seemed to me that probably the encrinital rock is more nearly related to the underlying than to the overlying strata, especially as it contains *Elæacrinus verneuili*, a characteristic form in the encrinital rock at Columbus. Yet in my dissertation I noted the fact that the encrinital rock may be above the horizon of the Columbus "bone-bed."[1]

It is to be noted, however, that Dr. Bownocker reported the Blastoid—*Nucleocrinus verneuili* (Troost)—from above the bone-bed in the quarries near Marion.[2]

SCHOEPFLE & SON'S QUARRY

This quarry is located on the eastern side of Hancock Street in Sandusky, and is the only one of the various quarries in that section of the city which is now actively worked. The following section was measured on the southern wall toward its western end:

No.		Thickness (Feet)	Total Thickness (Feet)
9.	Rather crinoidal limestone, which in the upper part is quite light gray in color. It contains *Spirifer duodenarius* Hall, and other fossils and corals are quite frequent near its top.	$2\frac{3}{4}$	$15\frac{3}{4}$
8.	Shale parting.	$\frac{1}{6}$	13
7.	Somewhat brownish-gray layer as weathered, containing crinoid segments, some corals, and small *Spirifers*.	$1_2^7{}_4$	$12\frac{5}{6}$
6.	Shale parting.	$2\frac{5}{4}$	$11\frac{1}{2}\frac{3}{4}$
5.	Bluish-gray limestone, not so even-bedded as lower layers, which also weathers rougher on exposed surfaces and contains a considerable number of cup corals, Crinoid segments, and small *Spirifers*.	$2_1^7{}_2$	$11\frac{1}{3}$
4.	Shale parting.	$\frac{1}{6}$	$8\frac{3}{4}$
3.	Bluish-gray, compact, fairly even-bedded limestones, the upper part of which is thinner-bedded. Building stone, moderately fossiliferous.	$3\frac{5}{6}$	$8_1^7{}_2$

[1] Letter of January 14, 1905.

[2] *Bulletin of the Science Laboratories of Denison University*, Vol. XI (1898), p. 27.

No.		Thickness (Feet)	Total Thickness (Feet)
2.	Black carbonaceous layer at top, with hackle tooth structure. *Tentaculites scalariformis* Hall is very abundant in the lower part of this zone, but decreases toward its top.	$\frac{3}{4}$	$4\frac{3}{4}$
1.	Massive bluish-gray limestone for building, about 1 foot of which is shown in this part of the quarry. Farther east there is an anticline shown in this wall of the quarry, and at its base beneath the crest about 4 feet of bluish-gray, compact limestone is shown beneath the Tentaculite zone to water-level. There are some *Tentaculites* in this lower rock, and in lithologic character it is not very different from No. 3 above the Tentaculite zone.	4±	4±

The surface of the layer forming the floor of the quarry on the northern side shows conspicuous ripple marks, which run about N. 30° W. and S. 30° E., with an average distance apart from crest to crest of about two feet. In the main, they measured from twenty-two to twenty-six inches apart, but they are not all uniform in separation, and occasionally two run together. This layer with the ripple marks is apparently about five feet three inches below the Tentaculite one. All of the rock in the walls of this quarry is of bluish-gray color, and weathers smooth until the base of the coral and crinoidal layers is reached. On the southern wall of the quarry these layers are conspicuous and project over the smooth underlying bluish-gray rock.

On the western side of Hancock Street, to the southwest of the Schoepfle quarry, and not far from the Lake Erie & Western Railroad, is a small abandoned quarry which, according to Mr. Schoepfle, was opened in 1874 by John Carr and Philander Craig. Near the top of the old quarry wall is a massive layer of bluish-gray limestone, the upper part of which contains fish bones, while its upper surface is rather rough and iron-stained, similar to the top of the Columbus limestone in central Ohio. Below the bone-bed the limestone contains numerous specimens of Brachiopods and corals, although they are not well preserved. The distance of this excavation from the southwest corner of the Schoepfle quarry is only a few rods, and the dip is apparently in that general direction, so that probably the rock of the Schoepfle quarry underlies the bone-bed of the Carr & Craig

quarry. A heavy storm, however, prevented the writer from determining this point, and perhaps the rather crinoidal limestone at the top of the Schoepfle quarry represents the lower part of the crinoidal limestone overlying the bone-bed. This latter view is the opinion of Dr. Swartz, who gives the total thickness of the strata in the Schoepfle quarry as nineteen feet.[1] In the next pit, a short distance to the southwest and nearer the railroad track, succeeding the layer containing the bone-bed is a massive, very crinoidal limestone, which on fresh fracture is brownish-gray to bluish-gray, but weathers on the exposed surface to a light gray color. There is shown above the bone-bed at least three feet of this crinoidal limestone when a layer of chert appears, and in part of the ledge six inches higher is another chert layer. Mr. Schoepfle also stated that, in working for other parties to the southwest of his quarry and west of Hancock Street, he found a considerable quantity of chert in the rock above the horizon of his quarry. Above the crinoidal zone the rock is thin-bedded to shaly, and *Leptæna rhomboidalis* (Wilckens) is abundant. This crinoidal zone apparently corresponds stratigraphically to the similar one noted in the Lake Shore & Michigan Southern Railroad quarry between Nos. 3 and 7 of that section.

To the south of the Carr & Craig quarry, between the two railroad tracks, is another old and abandoned quarry. The dip, however, is reversed, and the Schoepfle quarry limestone appears in this excavation with the bone-bed apparently at the top of the southern wall.

Still farther south, on Pipe Creek, by the northern side of the cemetery, is bluish-gray limestone, some of which is quite massive, which also belongs in the same division as that of the Schoepfle quarry. There is a heavy dip down-stream to the east at this locality, and the massive limestone is exposed up the creek well toward the western line of the Lake Shore Electric Railroad.

To the south of Sandusky, and about one-fourth mile south of the Soldiers' Home, is the quarry of the Wagner Stone Co. About eleven feet of rock is shown in this quarry, the upper three feet of which splits into thin layers from one and one-half to four inches in thickness, although not very even. The rocks of this portion are brownish-gray in color, and weather to a light gray or buff color.

[1] Letter of February 4, 1905.

The remaining part of the quarry has thicker-bedded layers, up to eighteen inches in thickness, although there are thinner ones used for flagging. The thicker layers which are used for building stone are brownish on fresh fracture, but, according to Mr. Wagner, weather to a bluish tint, and do not contain iron. In the lower part of the quarry is quite a massive layer, in which *Chonetes* sp. is common; but above this layer there are comparatively few fossils. In the upper layers, however, which are somewhat crinoidal, occasional specimens of *Strophеodonta demissa* (Con.) Hall, *Pholidostrophia iowaensis* (Owen) Schuchert, *Liorhynchus laura* Billings (?), and *Paracyclas elliptica* Hall (?) were seen. Much of this upper rock is marked with lines of bedding, and it is apparently quite an impure limestone.

To the west of the Wagner quarry, and just south of the Soldiers' Home, is the Hartman quarry, in which eighteen feet of rather even-bedded brownish rock is shown. This quarry extends stratigraphically about seven feet deeper than that of the Wagner Stone Co., and the rock is used largely for building. Fossils occur with about the same frequency as in the Wagner quarry, and the upper part of the rock is slightly crinoidal, similar to the upper layers in the former quarry. Both quarries show very little chert in any of the layers or partings.

CORRELATION OF LIMESTONE IN AND NEAR SANDUSKY

The Wagner and Hartman quarries just south of the Soldiers' Home and outside of Sandusky are correlated with the Delaware limestone of central Ohio.

The limestone in the Schoepfle and adjacent quarries in the city of Sandusky was named the "Sandusky limestone" in 1873 by Dr. Newberry,[1] who gave the localities at which it is quarried as Sandusky and Delaware. It has already been stated in this paper that at the time of Dr. Newberry's investigations the Schoepfle quarry was opened and studied by him; but the present quarries in the Delaware limestone to the south of the Soldiers' Home had not been opened. In Dr. Newberry's "Review of the Geological Structure of Ohio," published in the last strictly geological report issued under his direction, the name "Sandusky limestone" is retained for the upper division

[1] *Report of the Geological Survey of Ohio*, Vol. I, Part I, p. 143.

of what he called the Corniferous limestone, and the quarries at Sandusky and Delaware are given as localities of its occurrence.[1] It will be remembered that in this same volume Dr. Orton, in his "Report on the Geology of Franklin County," named the upper division the "Delaware limestone," "from its occurrence at Delaware."[2] In a paper describing fossil plants from the Corniferous limestone of Ohio, published by Dr. Newberry in 1889, occurs

FIG. 3.—Contact of Columbus and Delaware limestones in Lake Shore & Michigan Southern Railroad quarry two and one-half miles northeast of Castalia. The collecting-bag is on top of the Columbus, and the hammer indicates the superjacent shale.

the following sentence: "They [the fossil plants] are all from the Delaware limestone, the upper division of the Corniferous." A little farther on he speaks of "the white or Sandusky limestone below," apparently applying this name to the lower division of the Corniferous limestone; while he also stated that "the Delaware limestone is much darker and more earthy than the lower division of the Corniferous, and it is evident that it was deposited in shallower water when

[1] *Ibid.*, Vol. III, Part 1 (1878), p. 11. [2] *Ibid.*, p. 606.

the land was nearer and the land-wash more abundant."[1] The above statements apparently indicate that Dr. Newberry had abandoned his earlier opinion and now correlated the limestone in Sandusky with the lower division of his Corniferous or the Columbus limestone of central Ohio, instead of the upper division or Delaware limestone. There is, however, no definite explanation of this change of opinion in any of Dr. Newberry's works, as far as the writer is aware, and perhaps the above interpretation of this paper does not correctly represent him in this matter.

Dr. Charles K. Swartz, of Johns Hopkins University, in the fall of 1903 correctly determined the stratigraphic position of the limestones in the city of Sandusky, and correlated them with the Columbus limestone of central Ohio. He has thoroughly studied the various exposures of the Devonian limestones in Ohio, collected extensively in them, and carefully identified the fossils. Dr. Swartz has written me as follows regarding this subject:

> I find that nearly 87 per cent. of the species reported from the "blue rock" at Columbus and vicinity (including the section from the "smooth rock" to the "bone-bed") occur in that part of the Sandusky limestone in the Lake Erie region which I have referred to the Columbus formation. This includes the more diagnostic forms especially. I think the correlation thus rests on sufficient faunal evidence. Most of these forms do not pass above what I have termed the Columbus formation, or are quite rare in the upper division.[2]

In September, 1904, the writer studied the exposures in Sandusky, and fully agrees with Dr. Swartz in correlating all of the limestone, except the very highest layers, in the Hancock Street quarries with the Columbus formation. It is not improbable that the bone-bed noted in the old quarry on the western side of Hancock Street represents the well-known one in the Columbus region, which occurs at the top of the Columbus limestone, and at least the dividing line between the Columbus and Delaware limestones occurs not more than from three to six feet higher.

Since it is proved that nearly all of the rock to which Dr. Newberry gave the name "Sandusky limestone" belongs in the *lower* instead of the *upper* division of what he called the "Corniferous limestone,"[3]

[1] *Journal of the Cincinnati Society of Natural History*, Vol. XII, pp. 49, 50.

[2] Letter of January 14, 1905.

[3] *Report of the Geological Survey of Ohio*, Vol. I, Part I (1873), p. 143.

it appears to the writer that the name *Sandusky limestone* ought to be dropped. If it were now applied to the lower formation, it would cause serious confusion, since that was named at the same time the *Columbus limestone*, under which designation it is well known in geological literature. It is to be noted that in Dr. Newberry's classification and definition of these two limestones the name "Sandusky" appeared *first*, but on the same page as that of Columbus.[1] It is thought, however, that the above decision is in accordance with Rule 7 of the United States Geological Survey regarding "Nomenclature and Classification," which states that "in the application of names to members, formations, and larger aggregates of strata, the law of priority shall generally be observed, but a name that has become well established in use shall not be displaced by a term not well known merely on account of priority."[2] "Delaware limestone," published by Dr. Orton in 1878, is the next name applied to the upper division of the Devonian limestones of Ohio, and this is now adopted for this formation. In my paper on "The Nomenclature of the Ohio Geological Formations," published in the *Journal of Geology* in 1903,[3] "Sandusky limestone" was used for the upper formation of the Devonian limestones, because, as there stated, it antedated "Delaware limestone" by five years, and the error in correlation between the limestones of Sandusky and Delaware was not known to the writer. The thickness of the Delaware limestone in the Sandusky region, according to Dr. Swartz, is between forty and fifty feet, which is greater than that in central Ohio.

[1] *Loc. cit.*

[2] *Twenty-fourth Annual Report of the Director of the U. S. Geological Survey* (1903), p. 24.

[3] Vol. XI, p. 519, and see pp. 521 and 537.

MEGACEROPS TYLERI, A NEW SPECIES OF TITANOTHERE FROM THE BAD LANDS OF SOUTH DAKOTA

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(WITH PLATES III AND IV)

The Amherst College Palæontological Expedition of 1903, under the leadership of Professor F. B. Loomis, was remarkably fortunate in securing the greater part of a huge titanothere, apparently representing a species unknown to science which, aside from this, has the additional value of having the skull and limbs of one individual associated beyond doubt. The specimen was therefore deemed worthy of careful description, the privilege of which has been granted the writer through the courtesy of Dr. Loomis.

GEOGRAPHICAL AND GEOLOGICAL LOCALITY

The specimen was found by Mr. T. C. Brown, Amherst College 1904, near the head of Bear Creek, a tributary of the Cheyenne River in South Dakota. The exact locality was on the north side of Spring Draw basin, about ten miles from the mouth of Bear Creek. Here some two hundred feet of titanothere beds were found, lying upon Fort Pierre deposits, in which titanothere bones were discovered from a point six feet above the contact upward; the specimen under consideration lying thirty-five feet above the base of the beds, hence in the upper part of the lower division.[1]

If one may judge from the summary of characters given by Hatcher and others, the specimen would be considered a middle-bed form with some upper-bed characteristics, as it is far from being primitive.

CHARACTER AND CONDITION OF THE SPECIMEN

The skeleton, which is No. 327 of the Amherst College Zoölogical Collection, consists of a skull and jaws, the atlas, axis, and the fourth, fifth, and sixth cervical vertebræ. Nine dorsals, most of them spine-

[1] J. B. Hatcher, *American Naturalist*, Vol. XXVII (1893), p. 218.

less, are preserved, together with thirteen ribs. The lumbar, sacral, and caudal vertebræ are missing. Of the fore-limbs the proximal end of the left and the distal end of the right scapular are preserved, together with the distal ends of both humeri and the proximal end of the right.

The radius and ulna of the left limb and fragments of the right ulna represent the second segment; while of the manus all the bones of the right, except the pisiform, the trapezoid, and a few phalanges, are preserved, the left being less perfect, but supplementing the first so that, with the exception of a part of the humerus, our knowledge of the entire limb is complete.

The hind limbs are more complete, as both fermora, tibiæ, and fibulæ are preserved most admirably. Of the pes, that of the left limb is perfect as to the tarsus, while the right lacks only the ecto-cuneiform, that of another specimen being substituted in the mount. Both metatarsi are perfect, though several phalanges are missing. A number of sesamoids of both manus and pes are preserved, together with the left patella.

With the exception of the vertebral spines, the bones are for the most part in admirable condition, though the skull and jaws have been subjected to a peculiar shearing strain, which has brought the left side in advance of the right, as shown in the figures.

DETERMINATION OF THE SPECIES

The specimen under consideration is evidently a Megacerops, as the generic characters given by Osborn[1] and by Marsh[2] are well marked. The skull is moderately brachycephalic, with expanded zygomata; the horns are rather short, without a prominent connecting-crest, oval at the summit and transversely elongate oval at the base. The nasals are of moderate length, with well-rounded extremities. The dental formula is I.$\frac{2}{2}$; c.$\frac{1}{1}$; p.$\frac{4}{4}$; m.$\frac{3}{3}$; the two median superior and all of the lower incisors being represented by deep unclosed sockets, as though the teeth had been lost after death. There is a diastema behind the canines, and the internal premolar cingulum is less pronounced in the center of the tooth.

[1] H. F. Osborn, *Bulletin of the American Museum of Natural History*, Vol. XVI (1902), Art. VIII, p. 96.

[2] O. C. Marsh, *American Journal of Science* (3), Vol. XI (1875), p. 245.

Specifically the creature most nearly resembles *Megacerops bicornutus* Osborn and *Megacerops (Diploclonus) amplus* Marsh, having certain characters suggestive of each; but there are enough important differences to render it distinct and to warrant the erection of a new species for its reception.

Megacerops tyleri *sp. nov.*

Type No. 327 of the Amherst College Zoölogical Collection. Horns well in front of orbits, directed somewhat forward and outward, an elongate oval in basal section with the long axes in line, rounded oval at the summit. Hornlets quite conspicuous, on the inner face of the horns midway between the base and summit. Connecting-crest low and inconspicuous. Nasals broad, well rounded in front, and but slightly arched beneath. Zygomata expanded and deep, with a well-rounded outer face. Dentition: Superior incisors represented by the deep and well-defined median alveoli, and by the lateral teeth which remain in place, and which have hemispherical crowns which show little sign of wear. The canines are lanceolate, with a well-developed postero-internal cingulum. There is a short diastema in front of, and a longer one behind, the canine. Premolars with a smooth internal cingulum, less pronounced in the middle of the tooth, and with no external cingulum. The deuterocone is well developed, while the tetartocone, especially of premolar four, is inconspicuous.

The jaw is deep and robust, with the alveoli of two incisors, probably of the second and third, deep and distinct. There is no space between the lateral incisors and the canine, though between the two median alveoli a considerable gap occurs. There seems to have been a small diastema behind the lower canines, which are lanceolate, though with a less prominent cingulum, and not so strongly recurved as the upper ones.

COMPARISON WITH ALLIED SPECIES

The form under consideration resembles most closely *Megacerops (Diploclonus) amplus* Marsh and *M. bicornutus* Osborn, agreeing with both in the possession of hornlets, and with one or the other in minor characters, but differing in general contour of the skull and horns. The table on next page shows the main points of resemblance or contrast in the three species.

Professor Osborn, in his description of *M. bicornutus*, mentions as a cotype skull No. 1081 of the American Museum—a specimen with a somewhat checkered career, as it was first described and figured by Osborn in the *American Museum Bulletin*[1] as "*Titano-*

[1] Vol. VIII, Art. IX, pp. 176, 177.

M. tyleri, n. sp. Type No. 327, Amherst College	*M. bicornutus*, Osb.[1] Type No. 1476 A. M. N. H.	*M. amplus*, Marsh[2] Type in Yale Museum
Skull rather broad.	Skull narrow.	Skull rather broad.
Zygomata expanded.	Not expanded.	Expanded.
Outer face of zygomata rounded.	Rounded.	Acute.
Horns directed forward.	Nearly erect.	Directed forward.
Basal section elongate transverse oval.	Slightly oval sub-transverse.	Compressed transversely.
Hornlets on inner face half way to summit.	On anterior face less than half way to summit.	On inner face, one-third way to summit.
Connecting-crest low.	No connecting-crest.	Connecting-crest high.
Nasals broad, relatively short, rounded extremities.	Narrow, relatively elongate.	Short and narrow.
Nasals not highly arched beneath.	Highly arched beneath.	
Malar bridge not conspicuously sharp.	Sharp malar bridge in front of orbit.	Sharp ridge at base of horn core on the outside.
Canines lanceolate.	Rounded.	Lanceolate.
Diastema behind canines.	No diastema.	No diastema.
Premolars without external cingulum.	With external cingulum.	With external cingulum.

therium torvum (or *robustum*)." This skull resembles that of the specimen under consideration in general proportions, though in the former the horns are longer and more projecting. The teeth are badly worn and broken, but the one remaining premolar lacks the cingulum on the outside, as in the Amherst specimen. The canines are lacking, so that their character cannot be ascertained. Professor Osborn accounts for the differences between the type, No. 1476, and No. 1081 by the assumption that the former is a female skull, while the latter is that of a male. He states, however, that "the shape of the canines is the same in both sexes, but the male tusks are much more powerful than in the female."[3] Between the lanceolate canine of *M. tyleri* and the rounded canine of the *M. bicornutus* type there would seem to lie a specific distinction which, together with the other differences mentioned in the table above, would probably bring No. 1081 into the new species.

[1] H. F. Osborn, *loc. cit.*, p. 99.

[2] O. C. Marsh, *American Journal of Science* (3), Vol. XXXIX (1890), p. 523, Fig. 5; figured by Osborn, *loc. cit.*, Fig. 7.

[3] *Loc. cit.*, p. 173.

GENERAL DESCRIPTION

The skull (Plate III, Figs. 1–4).—The skull was partially exposed as it lay in the quarry, so that the occiput and the left zygomatic arch have been destroyed by weathering. The remainder is in admirable preservation, except for the distortion noted above. In spite of the fact that the union of the epyphises with the vertebral centra is as yet imperfect, which, as Marsh has shown, occurs rather late in the titanotheres as in the elephants, the sutures are almost obliterated from the skull, as one can only distinguish the squamoso-jugal suture

FIG. 1.—Basal section of the horns of *Megacerops tyleri* taken in a plane perpendicular to their axes. One-quarter natural size.

of the zygomata, and that on the inferior side of the nasals. The general contour of the horns is well shown in Plate III, Fig. 3, and in the sections here shown, though allowance must be made for the crushing backward of the right and the crushing forward of the left horn.

Toward the summit the horns become rounder in section, and they terminate in a much-roughened area, which is somewhat flattened, and which Osborn describes as "incompletely ossified." Another roughening of a similar character, though not so pronounced, marks the summit of each hornlet, and there is an entire absence of any vascular impressions over the surface of the horn, as in the horn cores of the hollow-horned artiodactyls and the Ceratopsia among dinosaurs. This leads the author seriously to doubt the accuracy of those restorations of the animal wherein these prominences are represented as sheathed with horn. On the contrary, it would seem, from the similarity of the roughened patches to those on the rhinoceros nasals, as though the entire prominence had been clothed with skin

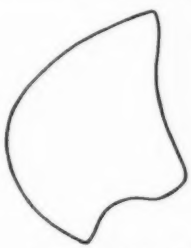

FIG. 2.—Vertical section through the zygomatic arch at the point of its greatest expansion. One-quarter natural size.

with two rhinoceros-like horns, a larger one at the apex and a smaller one on the summit of the hornlet.[1]

The missing portions of the skull have been restored from photographs of the American Museum skull No. 1081, already alluded to, which were loaned through the courtesy of Professor Osborn.

The skull measurements are as follows:

Premolar-molar tooth series	0.363
Premolars	.139
Molars	.227
Canine (crown) anterior length	.045
Canine (crown) antero-posterior diameter	.035
Premaxillaries to condyles (estimated)	.768
Nasals to mid-vertex (estimated)	.740
Transverse width of zygomatic arch	.583
Depth of zygomatic arch (buccal process)	.157
Nasals, free length	.084
Nasals, free breadth,	.140
Outside length of horn	.170
Expanse of horns	.393

Those of the jaw are:

Length, symphysis to condyle	0.685
Premolar-molar tooth series	.375
Premolars	.140
Molars	.235
Canine (crown) anterior length	.042
Canine (crown) antero-posterior diameter	.031
Depth of jaw	.355

In the lower premolar series a tooth is missing on each ramus, on the left the first, and on the right the second premolar, the missing ones being indicated by their roots. The molar series is well developed below and above, the hypocone of the third superior molar being well formed.

The atlas.—The atlas is a broad, heavy bone, with wide articular facets and expanded transverse processes. The spine is extremely low, and the short truncated hypopophysis extends backward. Of the foramina, only that for the dorsal root of the first cervical nerve is present, the ventral one, well shown in Palaeosyops,[2] being here

[1] Restoration of the Titanothere Megacerops. R. S. Lull, *American Naturalist*, Vol. XXXIX (July, 1905), p. 423, Figs. 2, 3.

[2] Charles Earl, *Journal of the Academy of Natural Science*, Philadelphia, Vol. IX, 2d series, Art. VI, p. 294.

represented by a deep notch as in the rhinoceros, which our specimen also resembles in the lack of a vertebraterial canal and in the relative widths of the anterior and posterior facets.

The dimensions of the atlas are:

Total width	0.320
Width across atlar-occipital facets	.204
Width across atlar-axis facets	.255

The axis.—The axis is a massive bone with a high neural arch, the spine being an equilateral triangle in mid-section. On its posterior face a shallow groove arises between the zygopophyses which fades out about two-thirds of the way to the summit. The prezygopophyses overhang the atlas in front, but present no articular facets. The odontoid process is a truncated cone, and is not so prominent relatively as in Palæosyops, being about one-third the length of the centrum measured along its inferior face. The latter exhibits a low longitudinal ridge below, but is not deeply excavated on either side, as in Palæosyops. The transverse processes of the specimen are broken away, but the bases of its two supports are seen, indicating the position of the vertebraterial canal, which is placed rather high on the centrum, though not on a line with its upper surface, as is Palæosyops.

The postzygopophyses look downward and outward; their horizontal axes, if continued, would intersect at an angle of 90°. Altogether both atlas and axis resemble those of a rhinoceros much more than those of Palæosyops.

The measurements of the axis are as follows:

Total height to summit of spine	0.295
Greatest breadth	.241
Length of centrum including odontoid	.133

The remaining *cervicals* are distinctly opisthocœlous, with zygopophyses which widely overlap one another. With the exception of the sixth, they are quite poorly preserved, and the sixth is so badly crushed as to make measurements very unreliable.

Of the *dorsals*, nine only are referable to the type specimen, though three others are added in the mount. The opisthocœlous centra are preserved, but the spines and transverse processes are lacking.

The ribs.—Portions of thirteen ribs from both sides of the body

are preserved. In general form they are quite rhinoceros-like, being somewhat widely expanded in the shaft. The capitulum is nearly spherical in most of the ribs preserved, and the two facets are separated from each other by a deep groove. In an anterior rib, the second or third, the tubercular facet, while mainly on the posterior side, arches over so as to lie in part on the anterior face. The other ribs have the tubercular facet entirely on the posterior face. The resemblances again are with the rhinoceros rather than with Palæosyops.

THE APPENDICULAR SKELETON

Fore-limb.—While both scapulæ are incomplete, they supplement each other so that our knowledge of them is fairly perfect. The proximal half of the left with its spine is well preserved, while of the right nearly the entire distal border is present.

The glenoid is deeply concave antero-posteriorly, and is broadly elliptical in outline. The corocoid process is conical, somewhat downwardly curved at the tip, separated by a deep notch from the glenoid border, and not arising directly from it, as in Palæosyops, but separated by an interval of 0.038 m. The spine is high in the middle, with a broad roughened border. It lowers insensibly into the general level of the scapular face above and below, with no indication of an acromion. The tuberosity is not very pronounced, and the distal border is nearly straight.

The dimensions of the scapula are:

Total length (estimated)	0.690
Width of superior border (estimated)	.405
Fore and aft diameter of glenoid fossa	.133
Height of spine	.095

The humerus.—The distal portions of both humeri are preserved, but of the proximal portions that of the right only, and as there is a portion of the shaft missing, the length cannot be measured. The distal end is broad and heavy, the external condyle being especially prominent and roughened for muscular attachment. The inner trochlear is much the larger and is higher than the outer one, thus indicating an outward flexing of the elbow joint. The aconeal fossa is large and deep, but there is no foramen. The breadth of the extremity measured at right angles to the axis of the shaft is 0.210.

Breadth of shaft	0.085
Fore and aft diameter of shaft	.077

The radius.—That of the left side is well preserved, except that its distal end is somewhat weathered. It is not notably heavy, and has a well-rounded shaft, but slightly compressed fore and aft at the distal end. The radio-scaphoid facet is prolonged upward on the posterior face, indicating a considerable range of flexion of the wrist.

The principal dimensions of the radius are:

Length	0.490
Antero-posterior diameter of mid shaft	.060
Lateral diameter of mid shaft	.065
Lateral diameter of lower end	.110

The ulna.—The entire left and fragments of the right are preserved, except for the distal end of the former, which is badly weathered. The ulna is notable for its huge compressed olecranon, which widens out distally into a heavy roughened tubercle.

The ulna measurements are as follows:

Length (estimated)	0.620
Antero-posterior diameter of olecranon from the humeral facet	.170
Lateral diameter of olecranon tubercle	.140
Fore and aft diameter of mid shaft	.080
Lateral diameter of mid shaft	.080

The manus (Plate IV, Figs. 1–3).—The general proportions well shown in the figure, are somewhat broad rather than slender and in direct correlation with the proportions of the skull. As has often been stated, the manus shows some distinctly artiodactyl features, the most notable being the retention of four digits with the main axis between digits 3 and 4, rather than lying in the third itself. Another remarkable feature is the extreme flexibility of the carpus, especially in the development of a true ginglymoid joint between the proximal and distal row of carpals. This is paralled in the carpus of *Rangifer caribou*, and is quite distinct from the condition found in the horse and camel, where, while the proximal facets of the distal carpalia indicate a certain range of flexion, there is no development of special pully-like ridges or keels, as in the titanothere and caribou. How this articulation is formed in the rhinoceros and tapir the author unfortunately has not had the opportunity to observe, but a compar-

ison would be most interesting. All of the elements are present in the carpus, with the exception of the trapezium, of which the last vestige has disappeared. The proximal facets are shown in Fig. 1 of Plate IV, though the limits of the radial and ulna areas are not with certainty definable.

The scaphoid articulates with the lunar by two facets separated from each other by a roughened trough. The superior scapho-lunar facet is long and narrow, its short axis vertical and straight, while its longer axis sweeps to the rear in a gentle convexity. It has the same antero-posterior extent as the scapho-radial facet above. The inferior scapho-lunar facet is much smaller, having but half the fore and aft extent of the superior. Distally the scaphoid articulates with the trapezoid and the magnum, and together with the lunar forms the deep groove into which the pully-like pivot of the magnum fits.

The lunar is a somewhat larger bone than the scaphoid, articulating distally both with the magnum and the unciform. The articulation between the lunar and cuneiform is again double, the two facets being separated by a well-defined channel, which runs backward and slightly upward. The two lunar-cuneiform facets are about equal in area. One can form a very good idea of the distal lunar facets by the study of their complementary facets figured in Plate IV, Fig. 2.

The cuneiform is about half the bulk of the lunar, and presents two facets on its inner face in every way the complements of the lunar-cuneiform. On the proximal face there is a large, saddle-shaped facet for the ulnar, and a smaller, semicircular, cuneiform-pisiform facet in the rear, set almost at right angles with the plane of the first. Distally there is a large cuneiform-unciform facet, having the general form of an equilateral triangle with rounded angles. It is again saddle-shaped, concave in its fore and aft axis.

The pisiform is lacking from the right manus, but that of the left is present and well preserved. It is much compressed laterally, with a deep vertical expansion of the distal end which is decidedly rugose. The bone presents a gentle, sweeping curve through an arc of nearly 90°. Proximally it bears two well-defined contiguous facets for articulation with the cuneiform and ulna respectively.

Of the distal row of carpals the trapezoid is absent, having been replaced in the mount by that from another individual. It is not a precise fit, there being some variation between its facets and those of the original bone.

The articular faces are well shown in the figure, and it will be noted that lateral movement is impossible, while a remarkable range of flexion is indicated.

The magnum has on its lower face facets for the articulation of meta-carpals 2 and 3, that for 2 being rectangular, about four times as long as wide. The pivot of the magnum is high and prominent, as indicated in the figure.

The unciform is the largest bone in the carpus, with the possible exception of the lunar. Distally it bears two facets for metacarpals 4 and 5, while on the radial side there is one which articulates both with the magnum and with metacarpal 3, the limits of the two articulations not being discernible.

A study of the distal carpal facets and the proximal metacarpal ones gives evidence again of more or less fore and aft movement, but in the case of the median metacarpals no lateral movement at all. The lateral metacarpals, on the contrary, were capable of lateral as well as fore and aft movement, so that, while the foot would spread somewhat when the creature's weight was borne upon it, it was all in the lateral bones. This would seem to be still further evidence that the true axis of the foot was between digits 3 and 4, as in the artiodactyls.

The principal dimensions of the manus are:

Width of proximal facets	0.170
Width of distal carpals	.170
Depth, lunar to summit of metacarpal 3	.080
Length of metacarpal 3	.250

THE HIND LIMB

The entire limb is figured in Plate IV, Fig. 4. There was no trace of the pelvis found associated with No. 327, though the limbs are in excellent preservation and give but little evidence of distortion by crushing.

The femur.—This is a fine bone, notable for its extreme flatness, which indicates the pillar-like posture of the bone, as in the elephant,

as the shaft would not have been sufficiently rigid to withstand springing, had the thigh been flexed. Another interesting feature is the absence of a third trochanter—a character given by Marsh in his definition of the genus Megacerops. There is a ridge on the outer side of the femur continuous above with the great trochanter, which probably represents the vestige of the third.

The measurements are:

Length	0.785
Width of proximal end	.236
Width of distal end	.204
Width of mid shaft	.117
Depth of mid shaft	.060

The tibia.—The general form of this bone is well shown in the figure, and calls for no special comment.

The measurements of the tibia are:

Length	0.446
Width of proximal end	.200
Depth of proximal end	.132
Width of mid shaft	.080
Depth of mid shaft	.077

The fibula is quite slender with expanded articular extremities.

Length	0.395

The pes.—The general proportions are in keeping with those of the manus. All of the tarsal elements are represented, with the exception of the entocuneiform which is entirely lacking.

The calcaneum.—The tuberosity is rather long and very rugous at its distal end, and with a much-flattened shaft which is about one-half as wide as long. The calcaneum bears facets for articulation with the cuboid, the astragalus, and on its upper outer face a small one for the articulation with the fibula.

The calcaneo-astragalar facet is somewhat saddle-shaped, its fore-and-aft axis being a reversed curve, first concave, then convex. The sustentacular facet, however, is deeply concave, the transverse axis curving through an arc of 90°, while the fore and aft axis is straight. Below there is but one facet, the calcaneo-cuboid, somewhat semilunar in shape, extending about half the width of the bone. Except for the articulation with the fibula, there is little evidence of movement between the calcaneum and the adjoining bones.

The astragalus presents a beautiful hour-glass-shaped, astragalo-tibial facet, bearing on its outer face a clearly defined fibula facet. The range of flexion and extension in the tibio-tarsal joint is considerable. Distally two facets are indicated, that for the navicular being by far the larger, and somewhat flattened, and with a small, prominent, downwardly projecting process, which effectually limits any fore-and-aft motion. A prominent ridge divides the two facets, that for the cuboid being an elongated triangle, first convex, and then concave from before backward.

The navicular is very flat and presents two distal facets, that for the ectocuneiform being the larger, and somewhat triangular in shape, while that of the mesocuneiform is semilunar, the line of demarcation between the two being almost straight.

The cuboid has a thickness equal to that of the navicular and ectocuneiform combined, and exhibits proximally two contiguous facets, the lesser for the calcaneum and the greater for the astragalus. Distally there are two facets, the external, the area of which is about four times the greater, being for metatarsal 4. This is somewhat saddle-shaped, while the other, that of metatarsal 3, is nearly flat.

The ectocuneiform is absent in the right pes, though present in the left, being replaced in the former by that of another individual. It articulates distally with metatarsals 3 and 2, though the latter articulation almost fades out anteriorly, broadening as one goes to the rear. This is markedly different from most titanothere feet which the author has seen, in which a wide line of contact is indicated on the face of the tarsus. There is, however, no possibility of contact between the mesocuneiform and metatarsal 3, as the former articulates distally with metatarsal 2 only.

The whole pes is remarkably rigid when compared with the manus, as there is little indication of any intertarsal movement, none between the tarsus and the median metatarsal, and no lateral and but little fore-and-aft play between the tarsus and the lateral metatarsals.

The principal dimensions of the pes are:

Width of astragalar facet	0.105
Length of calcaneum	.208
Width of the distal row of tarsals	.140
Height, astragalus to proximal end of the third metatarsal	.108
Length of the third metatarsal	.205

CONCLUSION

The general proportions of the skeleton would indicate a huge animal, seven feet four inches in height to the withers, and something over twelve feet in length, somewhat rhinoceros-like in aspect, but with more massive, pillar-like limbs, which, as Professor Osborn has shown, are correlated with great weight. The extreme flexibility of the carpus seems to indicate an elephant-like habit of kneeling on the wrists when rising and lying down. The creature was hardly adult, as indicated by the unossified vertebral epiphyses, though probably of full stature, and it indicated a form in the middle stage of evolution—a noble example of a splendid, though unfortunate, race. It is the author's privilege to dedicate this species to Professor John M. Tyler, of Amherst College, a teacher of men, who, by his earnest efforts as well as by his own generosity, was mainly instrumental in making possible the expedition which secured the specimen.

DESCRIPTION OF PLATES

PLATE III

FIG. 1.—Dorsal aspect of the skull of *Megacerops tyleri*. Drawn from the type specimen, No. 327 of the Amherst College Zoölogical Collection. The missing portion restored in outline. One-eighth natural size.

FIG. 2.—Lateral aspect of the skull and jaw of *Megacerops tyleri*, drawn from the type. One-eighth natural size.

FIG. 3.—Anterior aspect of the horns and nasals of *Megacerops tyleri*, drawn from the type. One-eighth natural size.

FIG. 4.—Incisor, canine, premolar series of upper teeth of *Megacerops tyleri*, drawn from the type. One-fourth natural size.

PLATE IV

FIG. 1.—Proximal aspect of the proximal row of carpals of *Megacerops tyleri*, drawn from the type specimen, No. 327 of the Amherst College Zoölogical Collection. One-fourth natural size.

sc., scaphoid; *lu.*, lunar; *cn.*, cuneiform.

FIG. 2.—Proximal aspect of the distal row of carpals of *Megacerops tyleri*, drawn from the type. One-fourth natural size.

td., trapezoid (drawn from that of another specimen); *mg.*, magnum; *unc.*, unciform; *sc. f.*, scaphoid facet; *lu. f.*, lunar facet; *cn. f.*, cuneiform facet.

FIG. 3.—Right manus of *Megacerops tyleri*, drawn from the type specimen. Lettering as above. One-fourth natural size.

FIG. 4.—Right hind limb of *Megacerops tyleri*, drawn from the type. One-eighth natural size.

cal., calcaneum; *as.*, astragalus; *cb.*, cuboid; *na.*, navicular; *cn*^{2}., mesocuneiform; *cn*^{3}., ectocuneiform.

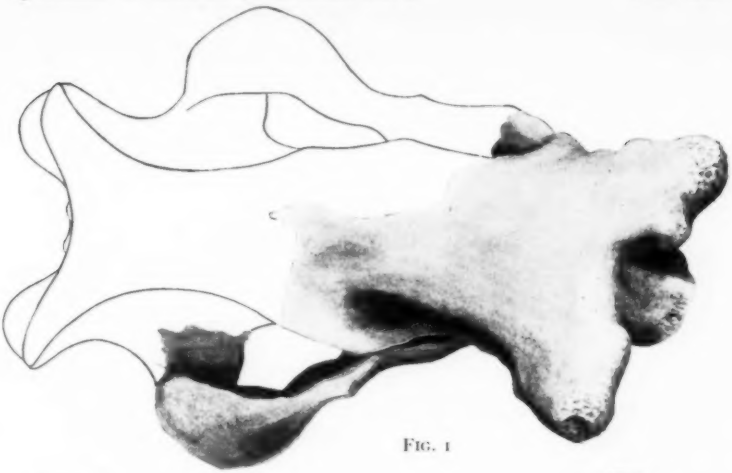

FIG. 1

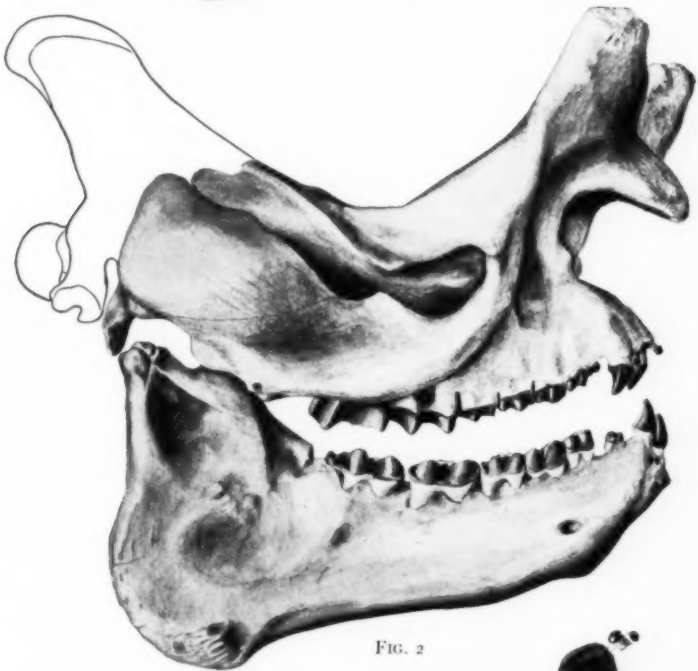

FIG. 2

R. S. LULL, del. ad. nat. FIG. 3

FIG. 4

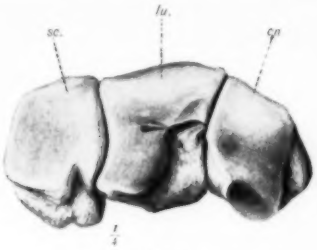

FIG. 1

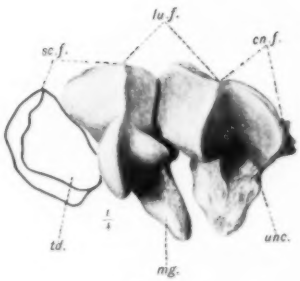

FIG. 2

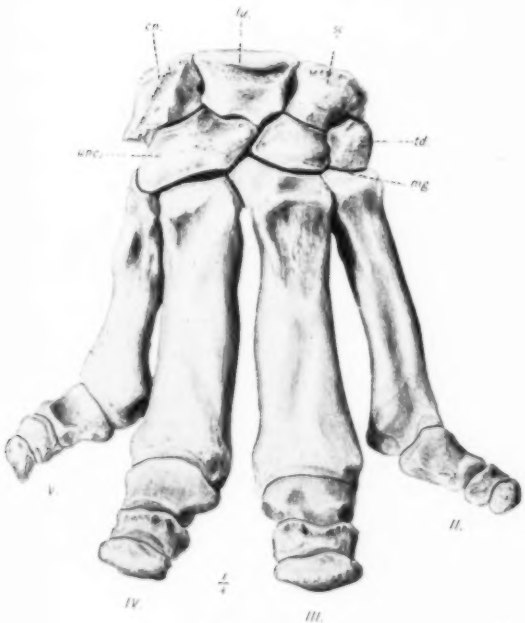

FIG. 3

FIG. 4

R. S. LULL, del. ad. nat.

COMMENT ON THE "REPORT OF THE SPECIAL COMMITTEE ON THE LAKE SUPERIOR REGION"

ALFRED C. LANE
Lansing, Mich.

In signing and assenting to the publication of the "Report of the Special Committee on the Lake Superior Region,"[1] it was agreed that the various members of the committee should have a right to add, or to publish elsewhere, notes explanatory of their subscription to the official creed. It may perhaps be worth the cost for me to explain why I was willing to accept "Laurentian" as a term apparently stratigraphic and co-ordinate with stratigraphic terms, though the formation is separated from the Keewatin (and Huronian?) by eruptive rather than unconformable contact—a kind of contact that I take not to have stratigraphic meaning.

If I had believed that this committee or any committee could make a final and binding determination of names, I should not have signed it, for I think the scheme will probably not prove to be final; but I did sign it as being the best practical working arrangement, with our present knowledge. Words are but labels for concepts, and our concepts must vary more or less as our knowledge increases, while it is desirable that our labels should remain as fixed as possible. I hope that the decision of the committee will prove to be the best that could have been done at present toward naming the rock formations so that future modifications will still apply the same names to most of the rocks involved. In the first place, I may frankly say that I have yet to see any rocks in the Laurentian, as defined by the committee, that I should class as a softened underlying formation. The granite and gneisses, etc., are crystallized from aqueo-igneous fusion, and have been at a temperature (under conditions) considerably beyond the consolidation point, as it seems to me,[2] as their grain shows.

[1] *Journal of Geology*, Vol. XIII, pp. 89–104.

[2] *American Geologist*, February, 1905.

At the same time, one who accepts Chamberlin's planetesimal theory must, I suppose, believe that all molten rocks have come from fusion earlier or later. But that would apply to all igneous rocks, and I do not see why it should involve a separate stratigraphic treatment of any, and these Laurentian granites, instead of being an immediately older formation, might be eras older. We find, however, able geologists, represented on the committee, who hold the subcrustal fusion theory probable or possible, and we find this theory implied in previous use of some of the Lake Superior stratigraphic terms; and I frankly own that I know of no conclusive arguments against it. Any agreement we may make as to the use of "Laurentian" is likely to be more or less of a compromise, and the problem is so to define terms that their application should be as far as possible the same, their extent represented by closely overlapping circles, whatever each man may privately think about the true inwardness of the connection of the rocks thus grouped.

The two terms the application of which we really had to delimit were Logan's terms "Huronian" and "Laurentian," and we have arrived at a temporory *modus vivendi* by using Lawson's "Keewatin" (Irving's "greenstone schists," Van Hise's "Mareniscan," Wadsworth's "Cascade," Rominger's "Dioritic group") as a buffer state.

One cannot fairly deny that Logan's idea of the Laurentian was a purely stratigraphic one, since it was divided into an upper and lower division, and that our proposed use of the term restricts it to part of the lower part of the same only. But the fact is that Logan founded the Laurentian and its divisions in eastern Canada. Then he came to Lake Huron, and for very good reasons erected another system, the Huronian, which in its most typical part is, we all agreed, younger than his Laurentian. So far we were led to the conventional arrangement of Archean, divided into Huronian and Laurentian, which one finds in most of the geological textbooks.[1] But, unfortunately (as it seems to me), Logan included in his original Huronian area a series of rocks, there relatively insignificant, green chloritic schists (3 *c* of Logan), which the committee report calls the Thessalon series. This series is, as we have said, intruded by granites, and it seems to me that the rocks are stratigraphically as low and temporally

[1] Dana, Giekie, Lapparent, Credner, Kemp's *Ore Deposits*, etc.

as old as any rock series that we now know. So here we have a clear case of overlap between the definitions of "Huronian" and "Laurentian." Moreover, we do not really know how far up in the Huronian the overlap extends, and this fact weighed much in my mind in favoring the final compromise. The Hastings series of the upper Laurentian is largely a limestone-dolomite series. So is the Mesnard series (or lower Huronian of the report) from the Gogebic Range through the original Huronian area north of Lake Huron, and it seems to me possible that the Mesnard series may prove to connect with the original upper Laurentian. If this should be so, it should of course be taken into account in drawing the line between Huronian and Laurentian.

Another factor complicates the situation, I am informed. Just as in going west from New York, through Ohio to Michigan, the only part of the original New York Lower Helderberg remaining was the Waterlime, the rest being absent by unconformity, and so the typical Lower Western Helderberg of Orton and Rominger corresponds to a member that some of the New York geologists are now inclined to prune off from the Helderberg entirely; so it has been with the Huronian. The chloritic schist type, so comparatively insignificant in the original Huronian area, if we have made no mistake, covers great regions and becomes very important elsewhere, and is essentially the formation Lawson called Keewatin, but has often been mapped as Huronian, while granite and light-colored gneisses have been mapped as Laurentian, without knowing or caring (so far as the mapping was concerned) whether they cut the green chloritic schists or not. To call these chloritic schists Laurentian would be to upset the nomenclature very extensively.

Moreover, we do not really *know* that the upper Laurentian may not be a formation older and beneath these chloritic schists, though I have not the slightest suspicion that it is. Thus it seemed well to retain for these chloritic green schists, so different in many ways from the Huronian, a name of their own, and among those used for them Lawson's seemed to have clear priority among geographical names. I must confess I am enough of a heretic to yearn personally for the good old descriptive terms like "greenstone schists."

"Laurentian" is thus left out in the cold as an accurately defined

stratigraphic term. It is a residual term under which all large old (or ill-known) batholiths or plutonic rocks may be grouped, and I presume will prove very convenient in this elastic sense. I shall use it about as Brooks used it. Those who believe in sub-crustal fusion will, however, use it, applying it to very much the same rocks, but implying more, that they are softened parts of the basement of the Huronian. It is hardly likely that the term will stay in this stage of definition very long. As the original Laurentian area is more carefully studied and its connections with Lake Superior made out, I presume we shall find out just about what proportion of the original Huronian must be taken from the bottom to be equivalent to the original Laurentian, and we should then revert to the original division of the Archean into the Huronian above and Laurentian beneath.

A few words, in conclusion, as to the top of the pre-Cambrian. Here, as usual throughout the geological column, there is difficulty in fixing the exact line of division. That the main part of the Lake Superior sandstone is Cambrian I have no question. It is, in fact, upper Cambrian apparently. A specimen with trilobites from the Menominee Range, Mr. C. D. Walcott determined as of the Ptychaspis zone. Wells at Grand Marais and Lake Linden show that at those points it has over a thousand feet of thickness.

Dr. Hubbard has proved conclusively to me that it overlaps unconformably on the base of the Keweenawan.[1] But does that imply that the Keweenawan belongs to a different system? Neither Seaman nor I think so. For while there is the unconformity with the base of the Keweenawan, and the Keweenawan is very thick, this thickness of thousands of feet is composed of rocks which accumulate with extreme rapidity. They are almost wholly sandstones, conglomerates, and traps. Geologically, the Keweenawan may represent no more time than some of our present volcanoes lasting from Tertiary times. Moreover, in such a series intra-formational, and even more intra-systemic discordances may be expected. As a matter of fact, we find bowlders and even agates of the Lower Keweenawan traps in the Upper Keweenawan. Yet there is a steady approximation, (1) in dips, (2) in stratigraphic distribution, (3) in disturbances,

[1] Vol. VI, Part II, pp. 110 ff.

(4) in lithological character, from the base of the Keweenawan to its upper portion, in the direction of likeness to the Lake Superior sandstone. (5) The deposition of this immense series must have been an era of subsidences, and the Lake Superior sandstone seems to have been formed through an area of subsidence; and outside certain limited areas like that near the Keweenawan fault there appears to have been no reversal of this subsidence between the Lake Superior sandstone and the Keweenawan, for the Lake Superior sandstone has but very little material that may be fairly supposed to have come from erosion of the Keweenawan. Its lithological character may be best explained as that of a bed mantling over the Keweenawan and deriving its material (frequently microcline) from the Laurentian granite bosses. But if the subsidence was not extensively broken and the Keweenawan is not Cambrian, then where are the middle and lower Cambrian?

The lithological character of the beds is such that fossils will hardly be found to help us. Of course, if Winchell proves to be right in saying that the Animikie is Cambrian, all the more would the Keweenawan be. But the Animikie is the kind of formation in which Cambrian fossils should be found, if present. I have never found them. The distribution of the Animikie and Keweenawan is quite discordant, and I think the Keweenawan much more closely associated with the Lake Superior or Potsdam sandstone.

Still, the argument above is not a coercive one. The true correlation of the Keweenawan is still an open question. And as the U. S. Geological Survey has consistently classed the Keweenawan as pre-Cambrian, I should not expect those at present in charge to change until convinced beyond question that in changing they were right. On the other hand, as my predecessors have classed the Keweenawan as Cambrian, and I believe them right, I cannot change. The only thing to do is to use the term "Keweenawan" or "copper-bearing," which is unambiguous, and avoid committing oneself, except in those formal classifications, where a formation must be placed in one pigeonhole or the other, and then only with due reserve.

Reviews

Géosynclinaux et régions à tremblements de terre ("Geosynclines and Earthquake Regions"). By F. de Montessus de Ballore. Bulletin de la Société Belge de Géologie. Brussels, 1905. Pp. xviii + 243–67.

This *mémoire* was read before the Société Belge de Géologie on December 20, 1904. The views presented are so suggestive that they are given here at some length, in order that the geologists of this country may promptly consider the theories advanced. M. de Ballore is well known as the compiler of the earthquake catalogue published in *Beiträge zur Geophysik*, Vol. IV, and the statistics have been turned to account in the article here mentioned. The author lays stress at the outlet upon the apparent influence of relief upon stability in the earth's crust, whether that relief be land or sea bottom. He then adds:

The seismic description of the globe has afforded two general results of great importance. One of them, the independence of seismic and volcanic phenomena, was already suspected. The other and quite unexpected one was the grouping of the earthquake regions of the earth into two narrow zones lying along two great circles of the globe. This purely geometric relation demanded a geologic interpretation. It was found at once on the maps: *These zones embrace the earthquake regions which coincide exactly with the geosynclines of the secondary epoch*, as represented by M. Haug in his well-known *mémoire* on the geosynclines and the continental areas.

Here is a general synthetic law clearly placing seismic phenomena under the direct control of the principal movements of the earth's crust, for it is along these lines that they have attained their greatest amplitude, both positive and negative. Depending entirely upon statistics and observations, and without the introduction of hypotheses, the law may be stated as follows:

The geosynclines, or the most yielding belts of the earth's crust where the sediments deposited to the greatest thickness have afterward, during the Tertiary epoch, been strongly folded and raised for the formation of the principal present chains or geanticlines, alone include, with only two or three doubtful exceptions, all the seismic regions. . . . .

Seismic instability cannot be uniform along these belts on account of the nonsynchronism of the movements and of the differences of amplitude. They include here and there peneseismic, and sometimes even aseismic, regions, the reason for which may be found in the details of geologic history. . . . .

The folded structure of geosynclines is unstable, while the tabular structure of continental areas is stable, and probably always has been so. Such is the law suggested by looking over the surface of the globe. It is therefore proper to divide the subject into several paragraphs corresponding to the five continental areas and the geosynclinal areas whose limits may be taken as known from the work of M. Haug. These are as follows, with the number of quakes in percentages of the total:

	Number of Earthquakes	Per Cent.
I. North Atlantic continent	8,939	5.21
II. Sino-Siberian continent	3,479	2.03
III. Australo-Indo-Malgache continent	374	0.22
IV. Africano-Brazilian continent	457	0.27
V. Mediterranean geosyncline	90,126	52.57
VI. Circum-Pacific geosyncline	66,026	38.51
VII. Pacific Ocean	2,033	1.19
Total	171,434	100.00

The geosynclines thus include 91.09 per cent. of the earthquakes that have been reported, as against 8.92 per cent. only for the continental areas, and that, too, in spite of their much larger land surface.

It may be objected that seismic observations are not old and not sufficiently known, except only for the North Atlantic continent, and that consequently this enormous preponderance of seismicity in favor of the geosynclines is more apparent than real, and that it is misleading on account of the lack of information regarding other continental areas. To this it may be replied that the complexity of geographic and geologic conditions of the North Atlantic continent as compared with the other four is not inconsistent with the larger number of quakes observed in the former, namely, 5.21 per cent. as against 3.71 per cent. noted for the last four. And even if we do not wish to take this argument into account, it must be admitted that at most the five continental areas cannot furnish more than 25 per cent. of the earthquakes, which would reduce to 75 per cent. in place of 91.08 the seismicity of the geosynclines, as compared with 8.92 per cent. of the continental areas. . . . .

It is not expected that the seismic problem will be completely settled by means of this synthetic law. But it is an important result that we can affirm on the strength of statistics the close relation between earthquakes and the zones of the earth's crust where the folds have attained their greatest energy at the same time that the vertical movements have reached their greatest amplitude. . . . .

There follows a brief discussion of the several continental and geosynclinal areas as listed above. The "North Atlantic continent" is defined by him, for purposes of discussion, as comprehending the region lying between the Rocky Mountains and the Urals and north of the Alps

and the Antilles. The "Sino-Siberian continent" lies between the Urals and the circum-Pacific and Mediterranean geosynclines. The "Australo-Indo-Malgache continent" is bounded on the east by the circum-Pacific geosyncline, on the north by the Mediterranean geosyncline, and on the west by the Mozambique channel. The "Africano-Brazilian continent" is spoken of as being astride of the South Atlantic and is bounded on the east by Mozambique, on the north by the Mediterranean, and on the west by the circum-Pacific geosyncline.

The Mediterranean geosyncline extends from Java and Sumatra across India, the Gulf of Persia, the Mesopotamian depression, southern Europe from the Caucasus to the Pyrennees, and the Mediterranean Sea to the Atlantic.

The circum-Pacific geosyncline extends from Cape Horn to Behring Strait and New Zealand, including the Antilles.

J. C. BRANNER.

STANFORD UNIVERSITY,
April 12, 1905.

Grundzüge der Gesteinskunde. Teil II, "Spezielle Gesteinskunde." By ERNST WEINSCHENK. Freiburg: Herdersche Verlagshandlung, 1905. Pp. 331, 8vo.

This work places in printed form a course of lectures given by Professor Weinschenk in the University of Munich, and designed to meet the needs of students already somewhat grounded in the general principles of petrology brought out in Part I, "Allgemeinen Gesteinskunde," which appeared several years ago. The volume is divided into three parts, treating respectively of the eruptive rocks, the sedimentary rocks, and the crystalline schists.

The eruptive rocks are treated in general according to the system of Rosenbush, each of the principal types being discussed in a very systematic manner under the following heads: (1) macroscopic characters; (2) mineral composition and structure; (3) chemical characters, and (4) occurrence and geological age.

The sedimentary rocks are treated under the usual divisions of mechanical, chemical, and organic sediments, and the principal types of rocks under each of these are quite fully discussed.

About thirty pages are devoted to the crystalline schists, the leading types being treated rather less systematically and in less detail than the types of eruptive rocks.

The illustrations are unusually good and are judicially selected; they include eight plates, and numerous illustrations and diagrams in the text. The characteristics of the various types of igneous rocks are well brought out in two tables. While valuable in a descriptive and historical way, many of the more theoretical portions of the book willl be regarded by American students as not entirely in accord with modern notions. This is particularly true of the author's treatment of metamorphism, which is still dominated by the older ideas of a stiff liquid condition during metamorphism, and into which the newer ideas of the continuance of a rigid condition do not enter.

E. S. B.

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